THE REORGANIZATION OF COLOR SYSTEM BASED ON MOGAO CAVE MURAL PAINTINGS

YI ZHANG

A Thesis Submitted to the Graduate School of Naresuan University

in Partial Fulfillment of the Requirements

for the Doctor of Fine and Applied Arts Program Degree in Art and Design

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has been approved by the Graduate School as partial fulfillment of the requirements for the Doctor of Fine and Applied Arts Program Degree in Art and Design of Naresuan University

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Title THE REORGANIZATION OF COLOR SYSTEM BASED ON MOGAO CAVE MURAL PAINTINGS

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ABSTRACT

The color of Mogao Cave murals has gradually been paid attention to in artistic creation and design with the development of the times. In the past, researchers' study of the color of Mogao Cave murals was limited to a particular aspect of color, such as technique and pigment, without forming a complete theoretical system of murals' color. Although the standard color system is whole, it is not fully applicable to the study of Mogao Cave mural color because of the different theoretical foundations and the differences of the times, which leads to the use of Mogao Cave mural color in art and design works is very singular and lacks systematicity and innovation. Therefore, the purpose of this paper is to collect and analyze data on many aspects of Mogao Cave mural painting color in the Northern Dynasties and the Tang Dynasty and to use methods such as the mixed research method, the documentary method, and the comparative method to formulate a new system of color in Mogao Cave mural paintings, and to produce outputs in the form of a book, which will be provided to art practitioners to be used in their artistic creations and designs. This systematic, clear, and practical approach to research provides a new system for using Mogao Cave mural painting color elements in artwork and design.

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Yi Zhang

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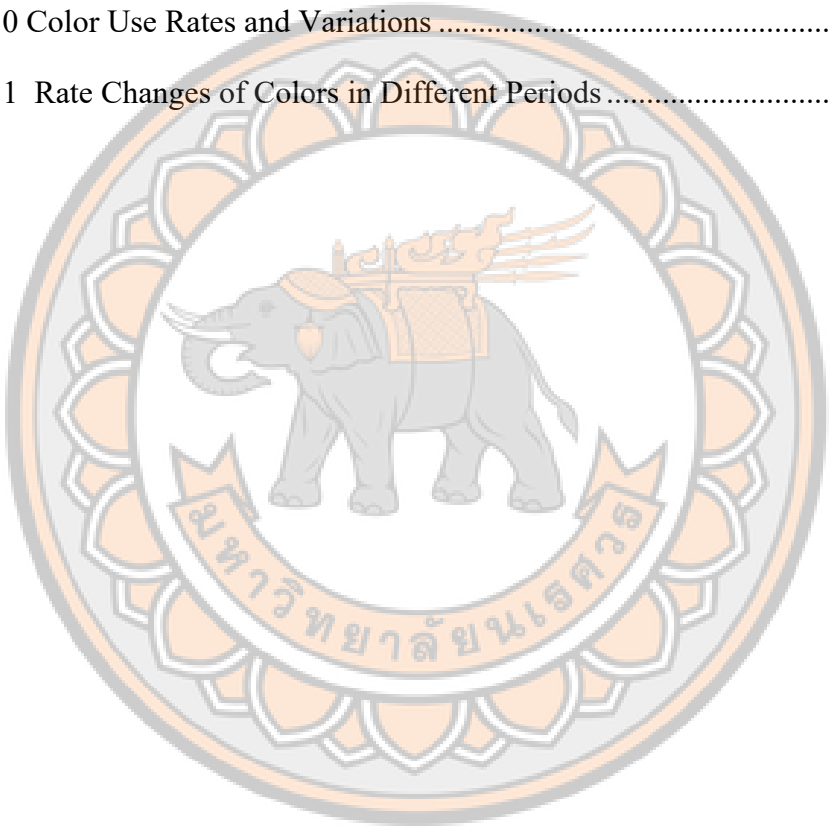

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CHAPTER I

INTRODUCTION

Overview

Chapter I provides an overview of this dissertation's research design, methodology, and objectives, entitled 'The Reorganization of Color System Based on Mogao Cave Mural Paintings. ' The chapter begins with an introduction to the research background, followed by problem identification, research argument, gap analysis, the significance of the study, research questions, and research goal and objectives. Subsequently, the research design will be delineated, including the sampling strategy, data collection methods, and data analysis techniques. The chapter concludes with a brief outline of the subsequent chapters, providing a roadmap for the dissertation's progression.

1.1 Background of The Research

1.1.1 Introduction to Dunhuang Mogao Caves Mural Paintings

Mogao Caves were established in the pre-Qin dynasty of the Shiliuguo period (366 A.D.) in the Dunhuang region of modern-day northwestern China. Mogao Cave has eleven formations, including the central tower pillar caves, the dipper-roofed caves, and the hall caves. Etc. Mogao Cave mural painting refers to the paintings painted on the walls of the caves. Existing Mogao Cave mural paintings from the Northern Liang Dynasty (397 A.D.) to the Yuan Dynasty (1368 A.D.) end, a total of 735 caves, of which 492 caves have mural paintings. The mural paintings, painted by many artisans who did not leave their names, are generally painted on all the walls and domes of the caves and include portraits of Buddha, Buddhist stories, Buddhist history, The sutra painting, portraits of providers, and sunk panel pattern, etc.

Dunhuang being an important trading port on the Silk Road, Buddhism began to spread in Dunhuang between the Shiliuguo period (366 A.D.), the Yuan Dynasty period (1368 A.D.), Dunhuang remained a Buddhist holy land connecting the Western Regions and the Mogao Caves were excavated at that time mainly for the Buddhist monks to practice and for the providers to offer their sacrifices to the monks, and the art of mural painting was initially used to disseminate the Buddhist culture and to decorate the caves.

The mural painting production is mainly based on the " Dry Mural Painting “technique, which is different from the " Wet Mural Painting " technique that appeared in the West in the thirteenth century.

Mogao Cave mural paintings of each dynasty’s style change represent different periods of people's aesthetic changes. In the early Northern Dynasties, the mural painting style was relatively primitive and rough. In the Tang Dynasty, the mural painting style was more gorgeous and exquisite, showing the heyday of Mogao Cave murals. After the Tang Dynasty, Mogao Cave mural paintings experienced a stylistic change. The style of Mogao Cave mural paintings once again transformed into a rough and exotic style. After the end of the Five Dynasties period, Mogao Cave mural paintings returned to being acceptable and delicate but no longer gorgeous. In the historical evolution of Mogao Cave, the peak period of the development of mural paintings was from the Northern Dynasties to the Tang Dynasty. Its mural painting style is complex and varied, reflecting the diversity of the development of the arts at that time and the aesthetic needs of the people of that time for the mural paintings.

1.1.2 The Narratives of Mogao Mural Paintings

Mogao Cave mural paintings are mainly based on Buddhist themes, including Buddha Preaching paintings, Buddha's life stories paintings, Jātaka stories paintings, the Sutra paintings, and other types of paintings. Buddha Preaching paintings are paintings that depict scenes from a sermon; Buddha's life stories paintings refer to the series of paintings and biographies of the life of Shakyamuni Buddha from his birth to Nirvana; Jātaka stories paintings tell the story of many deeds experienced by Shakyamuni in his previous reincarnations and the Sutra paintings refer to the explanation of the contents in the Sutra pictorially. The four types of Mural paintings in Mogao Cave are usually not categorized according to their content, and there are generally mixed of different types of mural paintings in a single cave. Different Buddhist themes also differ in the use of color in murals. In this study, four main types of Buddhist themes, including Buddha Preaching paintings, Buddha's life stories paintings, Jātaka stories paintings, and the Sutra paintings, are taken as the object of study to analyze the differences in the use of color in different contents.

As Indian Buddhism influenced the Mogao Cave murals, similarities with the Mogao Cave murals can be found in the surviving cave murals in India. There are traces of Jātaka stories paintings in the 1st century B.C. in India's Ajanta Caves, and according to the repainting in the 5th century, it can be seen that there is a consistency between the content of the Indian cave mural paintings and those in Mogao Caves. In the Xinjiang region, there are also the Kizil Caves, created by the ancient kingdom of Kucina (3rd century A.D.). The mural paintings in the Kizil Caves continue to be based on Buddhist themes and include Buddha's life stories paintings, Jātaka stories paintings, and other mural paintings. Similarly, a correlation can be found in the Bamiyan caves in Afghanistan. It can thus be seen that the caves on the Silk Road were mutually influential and closely linked.

1.1.3 The Evolution of Art Style and Color in Dunhuang Mogao Caves Mural Paintings

Mogao Cave mural paintings are inclusive in artistic style, both the learning and inheritance of ancient Indian painting techniques, and blend various ancient Chinese traditional painting characteristics. In terms of composition, the picture mainly adopts the decorative composition form of scattered points and flat columns. Regarding figure modeling, Mogao Cave mural paintings from the Western Wei Dynasty are fused with the modeling characteristics of traditional Chinese painting. During the Tang Dynasty, the emergence of the "Han statue" and "Sanskrit statue" were two different categories of figure modeling. In terms of the presentation of mural painting, usually, all cave walls have a mural painting in the form of a whole, cut, or serial painting.

The color of Mogao Cave mural paintings mainly uses the Indian "Shading and Highlighting Techniques of Hinduka." Although Mogao Cave incorporates many traditional Chinese painting techniques, the "Shading and Highlighting Techniques of Hinduka" have always been the primary color technique. The five colors of red, blue, green, black, and white are used as the basic colors, and the variation of colors depends on the way the colors are extracted as well as the different contents of gelatine and water added to the colors, resulting in variations in the shades of the colors.

Although the pigment materials of Mogao and Ajanta Cave mural paintings shared some similar methods, the paintings of Mogao Cave are unique in coloring style. For example, comparing the mural paintings of the 2nd cave of Ajanta Caves with those of the 461st cave of Mogao Caves, it can be seen that the colors of the Mogao Cave mural paintings are bold and bright. In contrast, the colors of the murals of the Ajanta Caves are less saturated and more subtle and softer. Although the same Shading and Highlighting Techniques of Hinduka are used, the colors in the mural paintings of Ajanta Caves are more three-dimensional. In contrast, those of Mogao Cave are more primitive. This indicates that the painting techniques of ancient India were already relatively mature during the same period, while the Mogao Cave mural paintings were in the stage of imitation and learning. Therefore, the performance was more straightforward. While learning foreign techniques and integrating Chinese painting techniques, the colors of Mogao Cave mural paintings developed their unique style.

Color is an essential part of mural paintings and has excellent research value, but the color elements of Mogao Cave mural paintings were seldom mentioned or discussed. The Northern Dynasty was the first peak of the development of Mogao Cave mural paintings. The Mogao Cave mural paintings of the Northern Dynasties are divided into four periods: the Northern Liang Dynasty, the Northern Wei Dynasty, the Western Wei Dynasty, and the Northern Zhou Dynasty. In terms of overall color style, the entire Northern Dynasties period went through three stages: foreign painting styles (Northern Liang and Northern Wei), the emergence of traditional Chinese painting styles (Western Wei), and the gradual fusion of Chinese and foreign styles (Northern Zhou). By the Sui Dynasty, Mogao Cave mural painting continued in the style of the Northern Zhou Dynasty. The Tang Dynasty was the second peak of Mogao Cave's development and heyday. The Mogao Cave mural paintings of the Tang Dynasty are divided into four periods: the Early Tang, the Flourishing Tang, the Middle Tang, and the Late Tang. The color styles of the Early Tang and Flourishing Tang periods were influenced by the Sinicization of Buddhism and more traditional Chinese paintings, which were more refined and delicate, with a more grandiose atmosphere. The artists also gave the mural paintings more humanistic feelings, which was the heyday of Mogao Cave murals. Since the Tang Dynasty gradually declined, the mural paintings of the Middle and Late Tang Dynasties were no longer grand. Still, they became more delicate and soft, and the color

styles were gradually homogenized and programmed. Therefore, in the Northern Dynasties and the Tang Dynasty period, Mogao Cave mural paintings are full of different styles and changes in color, rich and diverse, always showing the characteristics of the blend of Chinese and foreign styles. They are the main factors in the formation of the color style of Mogao Cave murals. Therefore, studying the colors of Mogao Cave mural paintings in the Northern Dynasties and the Tang Dynasty is essential to Dunhuang's research.

1.1.4 Color and Visual Effects

Color is usually directly related to the visual effect of art and design works, and different colors present different visual effects. Because of the different concepts of different periods, regions, and cultures, the performance of color is usually different. Such differences in color concepts eventually form different color systems. Therefore, the effect of the different fundamental theories of color is also different. For example, the use of color under the standard color system, the use of color in other contemporary color studies, and the use of color in the Mogao Caves and the same type of cave mural paintings all present different visual effects.

The color of the Mogao Cave mural paintings was primitive compared to the standard color system, and it had completely different characteristics from the standard color system. Firstly, the pigments were limited; only mineral pigments were used in Mogao Cave mural paintings. Secondly, the primary colors of Mogao Cave mural paintings were not derived optically but were determined by the limited variety of pigments available. Finally, the variations in the colors of the mural paintings are based on the different colors of the ores themselves and the various amounts of glue and water used, not on the mixing of multiple colors. Therefore, the standard color system cannot be used to analyze the colors of Mogao Cave mural paintings.

The embryo of the standard color system was Aristotle's relatively plain linear light theory of color, which was also relatively primitive at this time, emphasizing that colors were based on changes in light. By the time Isaac Newton used optics and physics to create a theory of light and color, the standard color system was, for the first time, backed up by a scientific theory, and for the first time, it was discovered that primary colors could be mixed to produce more colors. Then came Thomas Young's

physiological optics and the color light theory, and the standard color system gradually became complete. The entire common color system was based on optics and resulted from stage-by-stage demonstrations using the scientific method. After the Industrial Revolution, the West developed a method of chemically extracting colors, resulting in a wider variety of pigments and forming a pigment system with a transparent color system and higher purity. Standard colors formed a strong system with strict logic supported by theoretical systems and industrial technology.

Although the standard color system is complete, it does not apply to the study of the color of Mogao Cave mural paintings because of the difference in the theoretical basis and the era. The standard color system is based on optics. The main focus is to imitate the material world as seen visually, and the color representation is closer to the real world. More colors can be obtained through the mixing of primary colors. Therefore, familiar painting artworks usually have more color categories and minor color scale changes. Traditional Buddhist paintings, on the other hand, narrate more fictional stories and depict things, people, or environments outside of the world. Hence, the bold use of colors works with fewer color categories and more significant changes in color scale. Of course, the standard color system was introduced to China during the Qing Dynasty and influenced the color style of Chinese paintings.

In summary, the different color visual effects presented in art and design works are related to other regions, time, and cultural concepts. This difference in visual effects leads to the creation of different color systems. Chapter 2 will explain the specific analysis of the relationship between color and visual impact.

1.2 Problem identification

Formulating the color system of Mogao Cave mural paintings in the Northern Dynasties and the Tang Dynasty is very necessary. First of all, the color of Mogao Cave mural paintings is as important as the elements of modeling, composition, decorative motifs, etc., and the other elements have been relatively systematic research and use; in such a context, the study of the color system is indispensable, and the current research of the aspects of the color is relatively small, and there is no systematic research in terms of the color system. Secondly, in the protection of cultural relics, as mural paintings become more and more dislodged over time, there is a need for a more scientific and

systematic approach to the analysis and arrangement of colors. Thirdly, the number of Mogao Cave mural paintings is vast. The color of Mogao Cave mural paintings is quite different from the other color systems in terms of every aspect, so it is necessary to formulate an independent color system, and the writing of this thesis is helpful in the study of the color of Mogao Cave mural paintings completeness.

Since there are no systematic research results on the color of Mogao Cave murals, it is necessary to extract the colors of all the Mogao Cave murals in the Northern Dynasties and the Tang Dynasty and to do a more detailed color analysis by combining the context of the era, the content of the murals and the creator's ideas of painting, to form a complete system. As the Northern Dynasties and the Tang Dynasty period were the main periods of the development of Mogao Cave murals, they can be used as the central part of studying the color of Mogao Cave murals. At the same time, combined with the evolution of the color of the murals of other caves along the Silk Road, it can be used to explore further the cultural development history of the ancient Silk Road.

1.3 Significance of the research

In the study of the Mogao Cave mural painting color system, the first thing that needs to be done is a detailed analysis of the historical background of the color of the Mogao Cave mural paintings, the source of the pigment, the technique of color setting, the area of color use, and the meaning of the intrinsic colors. Etc. Secondly, the color extraction of Mogao Cave mural paintings is done to make a detailed color analysis. (Refer to Su Bomin's paper "The Research Process of Dunhuang Mogao Cave Mural Painting Pigments and Detection Techniques," published in Research on the Conservation of Cave Temples and Earthen Sites in 2022.) Finally, complete the systematic Mogao Cave color system.

The color of Mogao Cave mural paintings was an essential part of Dunhuang culture in the Northern Dynasties and the Tang Dynasty. In the study of color, as opposed to the separate analysis of all aspects of color, forming an independent color system is a systematic, precise, and more practical way of research. This is a new attempt to study Dunhuang mural painting culture and provides new ideas for using Mogao Cave color elements in real life. It will also play a positive role in the future use of color

elements in mural paintings, the integrity of the Dunhuang mural painting culture system, and more research on color.

This thesis will use a mixed method, documentary method, comparative method, statistical analysis method, and other methods in the research method to carry out the research.

The color of mural paintings in the Northern Dynasties and the Tang Dynasty is taken as the research object in the specific research content. The results of this study can provide a complementary color system for the study of early Mogao Cave mural paintings, which can be used for the analysis of color issues in Dunhuang and other caves along the Silk Road, expanding the scope of influence of Dunhuang color culture.

1.4 Research Goal and Research Questions

Goal: To reorganize the new color system based on Dunhuang Mogao Cave mural paintings with distinctive features. A case study of the mural paintings from Northern dynasties and the Tang dynasty.

Major question:

How can a color system be formulated using the Mogao Caves mural paintings from the Northern Dynasties and the Tang Dynasty?

Sub-questions:

1. What is the information about the four Buddhist- theme murals in the Mogao Caves?

1.1 What are the Mogao Caves mural paintings about?

1.2 What are the color features of the Mogao Caves mural paintings?

1.3 What is the intrinsic meaning of the color representation of the Mogao Cave murals?

2. What is the relationship between the color of the Mogao cave murals and the visual effects of art and design works?

2.1 What are the features of other color systems, and what benefits are they?

2.2 Why can't other color systems explain the color of Mogao Cave murals?

2.3 What is the visual effect of color in Mogao Cave murals?

3. How do we formulate the color system of Mogao Caves mural paintings?

3.1 What are the benefits of the Mogao Caves mural painting color system compared to other color systems?

3.2 What practical role can the formulation of the color system of Mogao Cave mural paintings bring in art and design?

1.5 Research Objectives

1. To collect Information on the color used in four Buddhist themes in Mogao Cave mural paintings

2. To relate the color used in Mogao Cave murals with the visual effects used for creating art and design works

3. To formulate an independent Mogao Cave mural painting color system focusing on the paintings created in the Northern Dynasties and Tang Dynasty

1.6 Potential Form of Research Outcomes

1 A summary report on the analysis of color information of four Buddhist- theme murals

2. A report on the visual effect relationship between the color of Mogao Cave murals and works of art and design

3. A book on the color system of Mogao Cave mural paintings

1.7 Research Scope and Limitations

1. This study's period is limited to the Northern Dynasties and the Tang Dynasty, excluding cave murals of other dynasties.

2. The Buddhist murals on the Silk Road in this study limit the scope of the Silk Road to the Land Silk Road and the Southern Silk Road, excluding the Maritime Silk Road and the Prairie Silk Road.

3. This study only aims to complete the color system of Mogao Cave mural paintings and does not involve using Mogao Cave color in specific art fields.

1.8 Research Benefits

1. Master the content, characteristics, and research status of four Buddhist themes murals, recognize the deficiencies in color research and find ways to make up for the shortcomings, and recognize the importance of formulating an independent color system.

2. This study helps to reveal the relationship between color and visual effect of the Mogao Cave murals, and provides color application methods for contemporary art and design creation.

3. Produce a book about the color system of Mogao Cave mural paintings so that more students and art practitioners can study it. This will provide new color experiences for the art field and indirectly create economic value.

1.9 Definitions

1. The central tower pillar caves: The Centre Pagoda Cave is derived from the Caitya Cave in India, where a stupa is enshrined.

2. The dipper-roofed caves: One of the cave forms. Plane square, open niches on the front wall. The cave roof center is square, with a deep concave sunk panel pattern, four sides of the slope, and shaped like an inverted bucket.

3. The hall caves: The hall cave is one of the cave forms. It is a plain square with a dipper roof.

4. Sunk panel pattern: The dome-shaped pattern inside the building is called " Sunk Panel." Each square is for a well and decorated with patterns, carvings, and paintings, so the name is Sunk Panel.

5. Portraits of providers: These are portraits of devotees who provided money, goods, or labor for the construction of the cave.

6. Dry Mural Painting: The art or technique of mural painting on dry lime clay.

7. Wet Mural Painting: Wet mural painting involves using durable slaked lime pigments first dissolved in water and then painted on freshly painted lime plaster clay walls.

8. Shading and Highlighting Techniques of Hinduka": This painting coloring technique from the Hinduka Lankava-Tara Sutra. It creates a three-dimensional sense of relief and convexity by forming tonal layers of light and darkness within the contour lines of the image, such as through the use of different shades of colors in a halo.

9. Buddha's life stories paintings: A series of biographies of the Buddha's life from birth to nirvana.

10. Jātaka stories paintings: The many deeds experienced by Siddhartha Gautama, the founder of Buddhism, in his previous reincarnations

11. Buddha Preaching paintings: Showing the scene of a sutra sermon. In the center is the Buddha, flanked by his disciples and Bodhisattvas.

12. The sutra paintings: A picture is used to explain the ideological content of a particular sutra.

CHAPTER II

LITERATURE REVIEW

2.1 Dunhuang Mogao Cave Mural Paintings in the Northern Dynasties and the Tang Dynasty

Mogao Cave murals of the Northern Dynasties and the Tang Dynasty are divided into Buddha Preaching paintings, Buddha's life stories paintings, Jātaka stories paintings, the Sutra paintings, Portraits of Providers, Sunk panel patterns, etc. In this paper, we only take the four main types of Mogao Cave murals of the Northern Dynasties and Tang Dynasty, including Buddha Preaching paintings, Buddha's life stories paintings, Jātaka stories paintings, and the Sutra paintings, as the research objects, and collect the basic information of these four types of Buddhist-themed murals.

2.1.1 Historical background

Dunhuang is located in the westernmost part of the Hexi Corridor, occupying two critical passes, the Yang Pass and the Yumen Pass. In 111 BC, Emperor Wu of the Han Dynasty set up Dunhuang County, and Dunhuang became a political, military, and cultural center on the Silk Road. As the Silk Road continued to flourish, Dunhuang, as an essential port of entry, became a place where Chinese and foreign cultures mingled and bumped into each other. (Ji.X.L.1998)

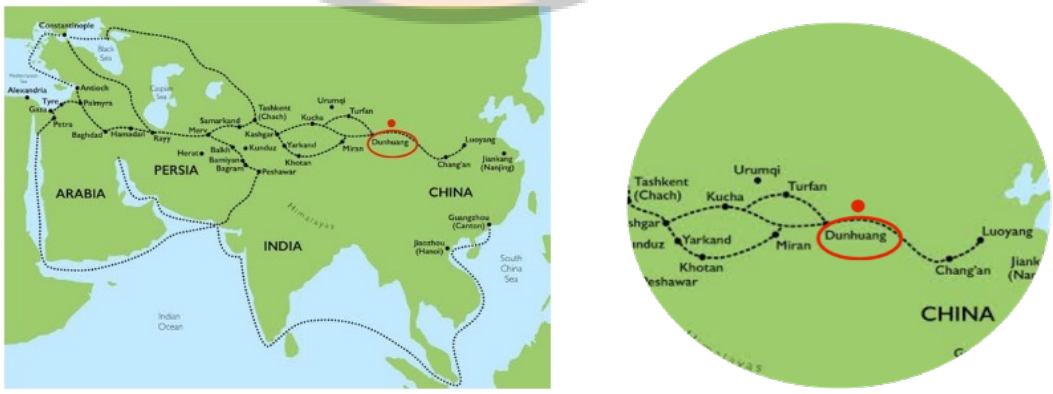


Figure 1 Location of Dunhuang
(Source: Khan Academy)

In 284 A.D., Buddhism was introduced to Dunhuang by the Kucina Kingdom, and Buddhism began to flourish in Dunhuang and the surrounding area. According to the Tang "Li Kerang rebuilt the Mogao Caves Buddhist monument" book of records, In the second year of Jianyuan in the pre-Qin period (366 A.D.), the monk Lezun passed by this mountain and suddenly saw the golden light shining, such as the appearance of ten thousand Buddhas, so he opened the first cave on the rock wall.

Figure 2 Exterior of the Mogao Cave
(Source: Dunhuang Academy)

Figure 3 Cave Distribution
(Source: Institute for Planets, 2023)

At the beginning of the establishment of the Mogao Caves, it was used for monks to meditate and practice, so the initial cave was only the Zen Cave. As the development of Buddhism grew, the Mogao Caves gradually became an essential place for people to worship the Buddha statue and hold Buddhist activities. Therefore, the scale gradually expanded, Statues and mural paintings gradually appeared in the caves, and cave types

were also gradually diversified; there are eleven types of caves, such as the central tower pillar caves, the dipper-roofed caves, and the hall caves.

Figure 4 From left to right: The central tower pillar cave, the dipper-roofed cave, and the hall cave
(Source: Dunhuang Academy)

The remaining caves in the Dunhuang area are Mogao Caves, Yulin Caves, East Thousand Buddha Caves, and West Thousand Buddha Caves. Mogao Caves is the largest, with the most caves, surviving statues, and mural paintings, so this dissertation will focus on it as the primary research object.

The Northern Dynasties was the first period in which the Mogao Caves were established and developed. The caves of the Northern Dynasties are divided into four periods: Northern Liang, Northern Wei, Western Wei, and Northern Zhou. According to the records in the book "Dunhuang Institute of Cultural Relics," Northern Liang is the earliest period of the existing caves (397-439 A.D.). It is the origin of Mogao Caves art. Three surviving caves from the Northern Liang period are Cave 268, Cave 272, and Cave 275. Cave 268 is a Zen Cave with a small area, no statues, and mural paintings on the walls. Cave 272 is a dipper-roofed cave with a prominent statue of the Buddha, mural paintings on the walls, and a Sunk panel pattern on the dome. Cave 275 is a hall cave with a central statue and two rows of smaller statues to the left and right carved into the cave. (Zhao. S. L. 2006)

Figure 5 Interior of Cave 275
(Source: Digital Dunhuang)

During the Northern Wei period (386-534 A.D.), since the Northern Wei after the destruction of Northern Liang, the war attacked the Dunhuang area, the excavation of Mogao Caves once appeared to be a break to the late Northern Wei period, the gradual recovery of religious art and culture, Dunhuang Mogao Caves excavation can continue, at this time the Indian religious art and Buddhism in the area of Dunhuang has been further developed, the content of the cave is also increasingly rich. Zhao Shengliang wrote in his article on the "Artistic style of Dunhuang's Northern Liang and Northern Wei murals" that caves in the Northern Wei period include 254 caves, 257 caves, 263 caves, and another 10 caves, basically imitating the Indian caves in the form of the central tower pillar system of the caves, more to meet the needs of the people to worship. The caves have carved statues, and the central niche is decorated with one Buddha and two Bodhisattvas. Mural paintings were on all four walls, and the sunk panel pattern was on the dome(Duan. W.J. 2002).

Figure 6 Interior of Cave 254
(Source: Digital Dunhuang)

During the Western Wei period (535-556 A.D.), the art styles of the Southern Dynasties began to influence Mogao Caves, and the art styles of Mogao Caves gradually diversified. The Western Wei period includes 246 caves, 285 caves, 431 caves, and another 10 caves, of which seven are for the central tower pillar caves and three are for the dipper-roofed caves. The contents of the caves and the Northern Wei period are the same.

Figure 7 Interior of Cave 285
(Source: Digital Dunhuang)

Northern Zhou (557-581 A.D.) is the last period of the Northern Dynasties. Still, the Dunhuang Mogao Caves Northern Dynasties period had the most significant number of existing caves. Mogao Caves has 14 from the Northern Zhou period (Fan. J. S. 2006). The caves of the Northern Zhou period are mainly single niche caves, and the center tower pillar caves, niches with a Buddha, two Disciples, and two Bodhisattvas, added two bodies of Disciples statues compared with the previous period.

Figure 8 Interior of Cave 301
(Source: Digital Dunhuang)

By the Tang Dynasty, the Mogao Caves were in their heyday. The caves of the Tang Dynasty are still divided into four periods: the Early Tang, the Flourishing Tang, the Middle Tang, and the Late Tang. Duan. Wenjie, in the article, "Innovating for the Mighty; An Overview of the Early Tang Mural Paintings in Dunhuang Caves," said: "The Early Tang Dynasty (618 - 712 A.D.) was the most vital period of the Mogao Caves, and the Tang Emperor Taizong's vigorous development of art and culture made the content and style of the caves gradually get rid of the influence of India, presenting a very distinctive Chinese traditional art style. There were 44 caves in this period, including Cave 57, Cave 335, Cave 431, and other caves. The primary forms are the central tower pillar caves and The dipper-roofed square caves, inherited from the Northern and Sui dynasties. The Giant Buddha Cave (Cave 96 and other caves.) and the Nirvana Cave also appeared. (Duan.W.J.2006)

Figure 9 Interior of Cave 57
(Source: Digital Dunhuang)

The arrival of the Flourishing Tang Dynasty (713-766 A.D.) marked the peak of the Mogao Caves' development. During this period, trade flourished in the Dunhuang area, and culture and art were exceedingly prosperous, so the Mogao Caves reached a whole new level of artistic expression. There are 81 existing caves from the Flourishing Tang period, of which Cave 41, Cave 45, and Cave 320 are representative. The shape of the caves began to be dominated by the dipper-roofed hall caves, with only a few central tower pillar caves (Shi. W.X. 2010).

Figure 10 Interior of Cave 45
(Source: Digital Dunhuang)

During the Middle Tang period (766-848 AD), also known as the Tubo period, Dunhuang was occupied by the Tubo after the Anshi Rebellion. The Tubo people dominated the construction of the Mogao Caves during this period. There are more than 70 significant caves, including Cave 258, Cave 159, and others. (Li.Q.Q. 2006). The dipper-roofed caves of the flourishing Tang period were continued, but the layout of the caves, statues, and mural paintings added a lot of Tantric content, which showed the foreign style of the Western region.

Figure 11 Interior of Cave 159
(Source: Digital Dunhuang)

According to the “New Book of the Tang Dynasty,” in 848 A.D., Zhang Yichao, a native of Dunhuang, staged an uprising in Shazhou, expelled the Tubo rulers, and led the people of Dunhuang back to the Tang Dynasty, Dunhuang formally entered the Late Tang Period. (848-907 A.D.) Zhang Yichao was made governor of Dunhuang after his return to the Tang Dynasty, where he ruled Dunhuang for 58 years. During the Late Tang Dynasty, more than 70 caves were excavated in Mogao Caves under the dominance of Zhang Zhichao's regime. The dipper-roofed front room and the central tower pillar in the back room of the mixed caves have appeared, such as Cave 9 and Cave 14. Large central Buddhist niche caves such as Cave 16 and Cave 94 also appeared (Guan. Y.H. 2001). Zhang Yichao family excavated a more significant number of the Merit Cave, which makes the content of the Mogao Caves in the late Tang Dynasty more secular life, such as Zhang Yichao's nephew excavated the 156 Cave, a detailed record of Zhang Yichao and his wife's travel scenes for the study of the late Tang Dynasty history to provide wealthy historical information.

Figure 12 Interior of Cave 156
(Source: Digital Dunhuang)

2.1.2 Mural Painting Content

Mural painting is an integral part of Mogao Caves art; according to the book "Dictionary of Dunhuang Studies,” Mogao Caves has a total of 492 caves with mural

paintings and colorful sculptures, of which 413 caves were excavated from the Northern Dynasty period to the Tang Dynasty period (Ji.X.L., 1998). Hence, the Northern Dynasties to the Tang Dynasty period is the main period of the development of mural paintings in the Mogao Caves, encompassing more than 80% of the mural paintings in the Mogao Caves. The content of the four main types of Buddhist-themed murals, Buddha Preaching paintings, Buddha's life stories paintings, Jātaka stories paintings, and the Sutra paintings, is summarized in this section.

1）Buddha Preaching paintings

In the Mogao Caves, Buddha Preaching paintings are essential in the murals, showing Buddhism's classic stories and teachings. Buddha Preaching paintings appeared in the murals of the Mogao Caves from the Northern Dynasties period. They continued to be the main content of the murals of the Mogao Caves until the Tang Dynasty. Among them, Shakyamuni Buddha Preaching paintings are the most shared content. They usually depict the Buddha Shakyamuni teaching Buddhist lessons to others after he attained enlightenment under the Bodhi tree. Such images often show the Buddha sitting on a lotus seat surrounded by disciples and devotees, showing the solemn scene of his teaching of the Dharma. (Li. X. J 2018) For example, the “Shakyamuni's First Turning of the Wheel of the Dharma” in Cave 96 of the Early Tang Dynasty, which depicts Shakyamuni Buddha preaching the Dharma in Deer Park, is a very famous Shakyamuni Buddha Preaching painting. (Xu. W. B 2010)

The Dharma Flower Sutra Buddha Preaching paintings are familiar in Mogao Cave murals. This theme usually depicts the narration of the Dharma Flower Sutra, and the murals contain images of the Buddha with his principal disciples and other audience members to emphasize the teachings and stories in the Sutra (Xu. W. B 2010). (Xu. W. B 2010) This kind of content is mainly found in Tang Dynasty murals, such as the Buddha Preaching paintings in Cave 105 during the flourishing Tang Dynasty, in addition to Buddha Preaching paintings such as Nirvana paintings, which show the Buddha's final preaching before he is about to enter nirvana, and Bodhisattva Preaching

paintings, which show Bodhisattvas (such as Guanyin, Manjushri, etc.) showing they teach the teachings of Buddhism.

Figure 13 Cave 57
Shakyamuni Buddha
Preaching paintings
(Source: Digital Dunhuang)

2）Buddha's life stories and paintings

Buddha's life stories and paintings focus on the life of Siddhartha Gautama, from his birth, initiation, spiritual practice, and enlightenment to nirvana. It shows the Buddha's life experiences as a mortal, an enlightened being, and a preacher of the Dharma. The familiar Buddha's life stories paintings in the Mogao Caves include the Mahamaya dream of a white elephant, the birth of the Buddha, the four gates of the Buddha's travels, the ascetic practice of monasticism, the attainment of enlightenment, the first turning of the wheel of the Dharma, and the Buddha's nirvana in seven elements. The most complete mural paintings in Buddha’s biography are the Buddha's life stories in Cave 290 during the Northern Zhou Dynasty, which show the birth of Buddha, his becoming a monk, and his attainment of enlightenment. (Zhao. S. L 2024)

Figure 14 Cave 290 Buddha's life stories paintings
(Source: Digital Dunhuang)

3) Jātaka stories paintings

Jātaka stories paintings are one of the essential subjects in the Mogao Caves murals, which mainly depict the stories of Shakyamuni Buddha's past lives of cultivation before he became a Buddha, showing him performing good deeds and accumulating virtues and sacrificing his life to save the living beings in many past lives. Through these images, Buddhist believers can feel how the Buddha continued cultivating and accumulating merits in countless lifetimes, finally achieving the fruits of Buddhahood. They are mainly found in murals from the Northern Dynasties period, such as "Jātaka of The King Deer with Nine Colors from Cave 257, Jātaka of The King Síbi" from Cave 254, and "Jātaka of Prince Sattva Sacrificing Himself to Feed a Tiger" from Cave 254, are very famous Jātaka stories paintings. Jātaka stories paintings often present the complete plot of a story through comic strips or continuous compositions, allowing the viewer to follow the story's development. (Li. K. N 2008)

Figure 15 Cave 257 Jātaka of The King Deer with Nine Colors
(Source: Digital Dunhuang)

04) The Sutra paintings

Sutra paintings are an essential subject in Dunhuang art, mainly depicting the storyline of Buddhist classics and the scenes and teachings of Buddhist scriptures. The Sutra paintings usually convey the deep meaning of Buddhist teachings through detailed images and complex compositions and show the story content of Buddhist classics. The Sutra paintings in the Mogao Caves are known as ancient Chinese Buddhist art treasures for their rich artistic expression and religious connotations. The Sutra paintings appeared during the Western Wei period and then frequently in the Mogao Cave murals. The Sutra paintings are usually based on stories from the Buddhist classics, showing scenes of the Buddha, Bodhisattvas, Lohan, Celestials, and believers and telling the stories and teachings of the classics through these images. For example, the Amitabha Sutra Painting from Cave 130 in the flourishing Tang Dynasty shows Amitabha Buddha guiding a person to the next life, expressing Elysium's majesty. The Avatamsaka Sutra Painting from Cave 156 of the Late Tang Dynasty includes the grandeur of the Avatamsaka world and the magnificence of the Buddha.

Figure 16 Cave 172 Sutra paintings
(Source: Digital Dunhuang)

2.1.3 The pigment sources in mural paintings

Yu. Feian, in his book “The Study of Colors in Chinese Paintings," expressed that pigments in Chinese paintings are mainly divided into organic vegetable pigments and inorganic mineral pigments. Mineral pigments were used in the murals of the Mogao Caves in the Northern Dynasties and the Tang Dynasty, and only a tiny amount of organic vegetable pigments have been found. This is a result of the limitations of the time and place; the Northern Dynasties and the Tang Dynasty were in an earlier historical period, and no more advanced sources of pigment were found anywhere in the world during this period. Which pigment was usually made by grinding minerals or extracting pigment from animal and plant bodies? In the “Book of the Later Han Dynasty” record, Dunhuang is located in the Gobi region, surrounded by mountains on three sides and connected to the Taklamakan Desert, which is a perennial drought with little rainfall and not many species of plants and animals but is surrounded by rich mineral resources. At the same time, Dunhuang was an important port on the Silk Road, with a well-developed commercial trade. Hence, the natural mineral pigments obtained

through local mining and trade became the primary source of color for the Mogao Cave mural paintings.

Mogao Cave mural paintings from the Northern Dynasties were painted in five colors: red, blue, green, white, and black; yellow is used occasionally. By the Tang dynasty, small amounts of gold foil began to be added as pigments in addition to the above colors. According to modern mural color composition detection technology, the original ore used in the Mogao Cave mural pigments was analyzed. Su. Bomin, in "The Research Process of Dunhuang Mogao Cave Mural Painting Pigments and Detection Techniques," expressed that Red from the pigment cinnabar (HgS) and earth red (Fe2O3 + quartz + clay) is one of the most frequent colors in Mogao Cave murals. Cinnabar comes from limestone, which is relatively stable; the color will darken under long-term light. Earth red comes from iron ore mixed with quartz, clay, and other mixtures(Su. B.M 2022), so the sharpness of the Earth red color varies.

Blue is also a color used more in Mogao Cave mural paintings, from the pigment azurite, mainly from the blue copper ore (Cu3(CO3)2(OH)2) and lapis lazuli (Na3Ca(Al3Si3O12)S), Lapis lazuli was introduced to Dunhuang from Afghanistan via the Silk Road, is an exotic pigment. The green color comes from the pigment stone green, usually sourced from malachite (Cu3(CO3)(OH)2) and chlorocopperite (Cu3Cl(OH)3); malachite and blue copper ore belong to the same substance, and the two are usually produced in conjunction with each other, but the colors behave differently.

White in mural paintings is often the base color, used frequently, the primary pigment for the chalk, from calcite (CaCO3), kaolinite (Al2Si2O5 (OH) 4), and other ores, chalk from more sources, the nature of the different. (Daisuke. O. 2019) Black is also one of the basic colors of Mogao Cave mural paintings, using pigments of carbon black (C), mainly from graphite, which is stable and not easy to fall off.

Gold foil is a pigment made of gold (Au) pressed from the source of gold ore, which is stable and not easy to come off. It began to appear in mural paintings during the Sui and Tang dynasties. The primary source of yellow is goethite (FeO (OH)) and gold stone (As2S3); iron yellow from goethite and gold stone can be extracted to produce two types of pigments, loess and orpiment. Yellow is unstable, prone to discoloration, and is a very precious and rare pigment, but in the mural paintings of the Mogao Caves, it appeared significantly less. The specific summary is shown in Table 1:

Table 1 Pigment Ingredients and Characteristics Analysis

Color	Pigment	Ore	Chemical Formula	Quality
Red	Cinnabar	Limestone	HgS	Stable
	Earth Red	Iron Ore	Fe2O3+ quartz +clay	Instability
Blue	Azurite	Blue Copper Ore	Cu3(CO3)2(OH)2	Stable
		Lapis Lazuli	Na3Ca(Al3Si3O12)S	Stable
Green	Stone Green	Malachite	Cu3(CO3)(OH)2	Stable
		Chlorocopperite Ore	Cu3Cl(OH)3	Stable
White	Chalk	Calcite	CaCO3	Instability
		Kaolinite	Al2Si2O5(OH)4	Stable
Black	Carbon Black	Graphite	C	Stable
Golden	Gold Foil	Gold Mine	Au	Stable
Yellow	Iron Yellow	Goethite	FeO(OH)	Instability
	Orpiment	Gold Stone	As2S3	Instability
	Loess			

Organic pigments are mainly extracted from plant and animal bodies, and according to Wang Jinyu et al. 2018, the primary organic pigments in Mogao Cave mural paintings are indigo, garcinia cambogia, violet gelatinous red pigment, and Phellodendron amurense. Indigo is the oldest organic pigment known to humanity and is mainly extracted from polygonum, Isatis tinctoria, and Indigofera tinctoria Linn, which contain indolic acid components. Garcinia Cambogia is also taken from the plant and contains primarily ketones and triterpenoids represented by Garcinia Cambogia acid. The violet gelatinous red pigment is a metabolic product of the Lacciferlacca. Phellodendron Bark dye is dominated by alkaloidal polar molecules, with berberine as the main component. Due to the nature of organic pigment and its instability, there are severe fading and color change phenomena.

2.1.4 Mural Paintings Coloring Techniques

In the “Dictionary of Dunhuang Studies” compiled by Ji Xianlin, it is recorded that in the Northern Dynasties and the Tang Dynasty, mural painting coloring techniques

were Shading and Highlighting Techniques of Hinduka, and flat dyeing techniques were dominant.

Shading and Highlighting Techniques of Hinduka is a painting coloring technique recorded in the “Lankava-Tara Sutra.“ Overlap dyeing different shades of colors within the contour line of the figure constitutes the light and dark changes of the tonal levels, and the picture finally presents a hierarchical, colorful, and three-dimensional effect. (Li.J. 2012) The mural paintings of the Northern Dynasties mostly used this method in painting figures. (Duan.N.2019) The initial imitation and learning of the Shading and Highlighting Techniques of Hinduka can be seen in the mural paintings of the Northern Liang period. Still, because the technique is not yet well-developed, the figures’ colors in the Northern Liang period mural paintings do not have a strong sense of hierarchy and three-dimensionality.

After the Northern Wei period, Hinduka’s use of Shading and Highlighting Techniques gradually matured. For example, the characters in the " Jātaka of Prince Sattva Sacrificing Himself to Feed a Tiger " in Cave 254 of the Northern Wei period can be seen to have a clear hierarchical and three-dimensional sense of expression from the face to the body. Another example is the portrait of the Bodhisattva in Cave 428 of the Northern Zhou period, in which the facial coloring of the characters is varied and very vivid.

By the Tang Dynasty, traditional Chinese painting techniques developed rapidly. Chinese painters improved the Shading and Highlighting Techniques of Hinduka, and halo dyeing techniques appeared. Since then, overlap dyeing has gradually been replaced by halo dyeing, and the Shading and Highlighting Techniques of Hinduka have developed a whole new look in China. This technique has always been used in traditional Chinese paintings. (Gu.Y. 2000) Halo dyeing techniques made the colors lighter and softer, making the murals’ color expression after the Tang Dynasty more prosperous and diverse. Shading and Highlighting Techniques of Hinduka have been the primary coloring technique for Mogao Cave mural paintings, and this method continued until the Song and Yuan dynasties.

In addition to the Shading and Highlighting Techniques of Hinduka, Mogao Cave mural paintings also used the flat dyeing technique as a coloring method. Flat dyeing involves filling in color directly within the contour lines and is usually used for

backgrounds, patterns, and clothing. (Ma, Y. H. 2009) During the Western Wei period, the Southern Dynasties gradually influenced the Dunhuang area, and mural paintings of figures began to take on the style of traditional Chinese painting, with more use of the flat dyeing technique. For example, in the Portraits of Providers in Cave 285, the depiction of the figure's face and clothing was not Shading and Highlighting Techniques of Hinduka, but rather the flat dyeing technique, which gives it more of the style of traditional Chinese painting. (Dun, W. J. 2006) This style of coloring continued to be favored by painters during the Sui and Tang dynasties and was more often used in decorative patterns.

In addition to the two main coloring techniques mentioned above, the gold leaf method of the Sui and Tang dynasties began to be popular in the Mogao Caves mural paintings. Zhao Zhenghui, in the article "Foil in Painting Research," said that the gold leaf method is mainly used by placing gelatine gold foil on top of the screen to create a decorative effect on the picture. This technique in the Sui and Tang dynasties was often used to decorate the characters' clothing and faces.

Mogao Cave mural paintings of the Northern Dynasties and Tang Dynasty are relatively simple in their coloring techniques. They are mainly based on Indian painting techniques but also incorporate the coloring techniques of traditional Chinese painting. Later, localized improvements were made to the Shading and Highlighting Techniques of Hinduka, which gave the mural paintings of each period a different style.

2.1.5 The Narrative of the Mural Paintings

In the article “A study of coloring in Dunhuang murals of the Tang and pre-Tang dynasties and its influence in modern painting," Pan Wenxun states that early Dunhuang mural painting was a direct-color painting that maintained and developed a vivid, atmospheric, fluent style.

Firstly, although pigments were limited, its bold use of decorative colors, unique overlap dyeing technique, halo dyeing technique, and coloring technique are the source of future generations of mural painting and even the development of the art of the first reference (Ma Y.H. 2009).

Secondly, the painters and artisans of ancient Dunhuang incorporated the talents and creativity of the peoples of northwestern China, and they were inspired and

stimulated by the religions and arts of India and Iran. They were courageous in their approach to change and innovation, utilizing their rich imagination and unparalleled enthusiasm. (Chang. S.H. 1982)

Thirdly, the Northern Dynasties and the Tang Dynasty were the main periods of the development of Mogao Cave mural paintings, during which the color style of Mogao Caves mural paintings through a total of three periods: Northern Liang, Northern Wei period, the initial study of Indian color techniques, this period of murals color style foreign style is remarkable. Western Wei and Northern Zhou periods of traditional Chinese painting techniques gradually evolved into the Mogao Cave mural paintings, combining Chinese and Western characteristics. During the Tang Dynasty, the heyday of Mogao Caves mural paintings, both in the resources of painting pigments and the development of traditional Chinese painting techniques, have been greatly improved; Mogao Caves mural paintings show a unique Chinese style. Finally, the Mogao Caves mural paintings in the Northern Dynasties and the Tang Dynasty have a variety of color styles, ranging from bright and bold to gradually exquisite and delicate, with a high degree of recognition.

Color is an essential part of mural paintings and has significant research value. The world gradually noticed Dunhuang mural painting culture; its mural painting shape, composition, and decorative patterns have become the representative elements of Dunhuang culture. In contrast, the color element of Mogao Cave mural paintings is seldom mentioned and discussed; the study of color depends on the shape of the other aspects or the analysis is done from an optical restoration point of view. Therefore, separating color from different elements to form an independent system is necessary for studying Mogao Cave mural paintings. The color of Mogao Cave mural paintings in the Northern Dynasties and the Tang Dynasty not only laid the foundation for the subsequent development of Mogao Cave mural paintings but also connected the bridge between Central Asia and India on the Silk Road mural painting art and Chinese mural paintings art. Hence, studying the color system of Mogao Cave mural paintings in the Northern Dynasties and Tang Dynasty is indispensable.

To sum up, studying mural painting color in the Northern Dynasties and the Tang Dynasty period as an independent research object and forming an independent color system is a new attempt to study Dunhuang mural painting culture. This positively

affects the study of Dunhuang mural painting culture and provides new ideas for using Dunhuang color elements in real life.

2.2 Common Color Theories

2.2.1 Origin and Development

The standard color system is based on optics, and after continuous research and evolution, a scientific, systematic, and theoretical system is formed. The standard color system can be traced back as early as 384 BC when Aristotle put forward the linear light color theory; theory advocates that all colors are composed of light and darkness; although it is a simple natural science theory, it can be seen from then on the standard color system is based on the light source. Since then, the West has widely adopted this theoretical system, during which Hasan Ibn al-Haytham first proposed a scientific method to prove the color theory; Franciscus Aguilonius first proposed the idea of three primary colors, which contradicts Aristotle's binary color theory.

It was not until 1704 A.D. that Isaac Newton proposed in his book “Optics” that colors are not made up of black and white but of white light. This discovery redefined light and color. Newton redefined primary colors and created the color wheel, a milestone in developing the standard color system. To this day, Newton's color theory remains the root of the standard color system. Since then, scientists have also gradually begun associating color with perception, and people have started to pay attention to visual color. In the 18th century, the British scientist Thomas Young discovered a new theory: light appears in the form of waves, which is an essential breakthrough in the visual color theory, through which he concluded that mixing different proportions of the primary colors can get new colors, which further strengthened the standard color system systematic. At the end of the 18th century, Josef Albers gave primary, secondary, and tertiary color schemes in his 1963 book “The Interaction of Color,“ in which he argued that the context of each color strongly influences human perception of color. Today, colors are gradually associated with age, gender, personal background, emotions, and social factors (Alexander, 2022). Western researchers continue to explore new functions and possibilities of color.

2.2.2 Concept of Primary Colors

Primary colors are fundamental concepts in color theory. Primary colors are basic colors that cannot be derived through blending and are based on the physiological effects of the naked eye on light. The concept of primary colors existed in ancient times. Forty thousand years ago, people extracted the five colors of red, yellow, brown, black, and white as primary colors from limited resources （Alexander, 2022）, and the primary colors at that time were based on the substances' colors. In modern times, Newton redefined red, green, and blue as the three primary colors, and since then, the concept of primary colors has been using Newton's definition of primary colors.

Based on the primary colors, derived by mixing the primary colors two by two, derived from the red + green = yellow, blue + green = cyan, blue + red = magenta, three secondary colors, and then by mixing a part of the primary colors with half of another primary color, derived from the tertiary color, this third-order color system can be derived from a wide variety of colors, The above is a theory of additive three primary colors based on optics. Later, the subtractive primary color theory emerged, with the secondary colors of yellow, cyan, and magenta as the three primary colors. This theory is often used to mix pigments, and the blending of pigments in paintings and sculptures is usually based on the theory of subtractive primary colors. This shows that combining a great variety of colors through primary colors is an essential part of the standard color system, which also reflects the richness of the use of colors in Western artworks.

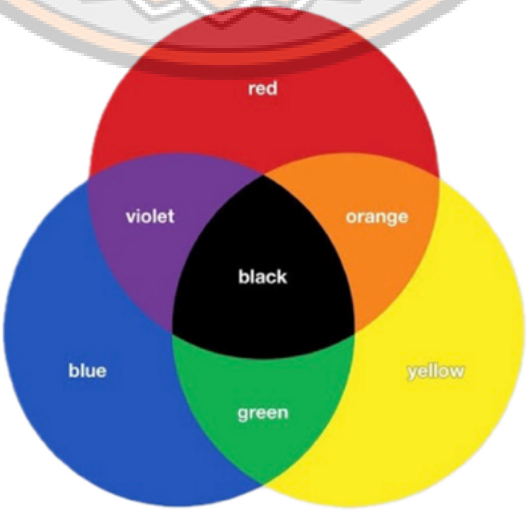


Figure 17 The subtractive primary color
(Source: Britannica)

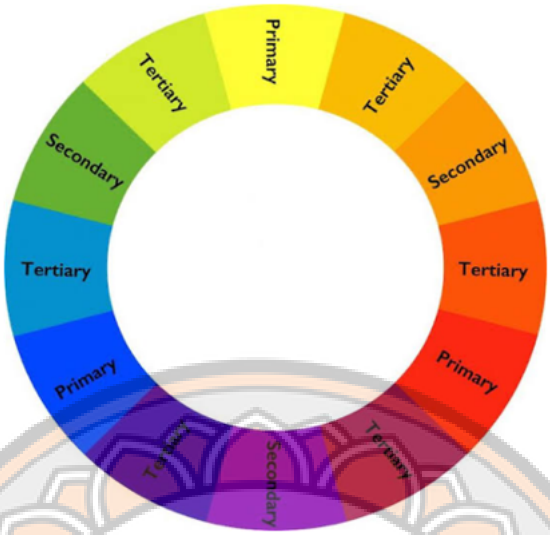


Figure 18 Tertiary Color Theory
(Source: Public Domain)

2.2.3 Generation of Pigments

In the standard color system, pigments come from a variety of sources. In primitive societies, people learned to extract colors from soil and charcoal to make natural inorganic pigments. Before the Industrial Revolution, most of the pigments in the West came from ores, plants, and animal bodies. Pigments were taken directly and extracted relatively simply, often through grinding, washing, precipitation, burning, and other ways of extraction and production, and animal and plant oils were added to blend the pigments when they were used.

After the Industrial Revolution, Westerners developed a way of extracting pigments chemically. In 1704, Diesbach developed a method of making Prussian blue, which was then put into large-scale industrial production. In the 19th century, ultramarine, chrome green, chrome yellow, and other pigments were produced industrially (Lowengard. S. 2006), and synthetic pigments gradually replaced natural inorganic pigments, becoming the primary source of pigments in the West. Since then, Western painting pigments began to be progressively enriched, and a pigment system with a transparent color palette and higher purity was formed.

In the 20th century, scientists focused on researching and developing environmentally friendly pigments that did not contain harmful heavy metals, and

various high-performance composite pigments appeared. So far, the development of pigments in the West has formed a relatively complete system and scale of production, and newer pigments are still being developed.

2.2.4 The Relationship between Light and Color

Optics is the foundation of the standard color system, and light and color are inseparable in Western art. Classical Western painting focuses on the perception and reproduction of the real world, so most of its colors are imitations and reductions of light shadow representations of the real world. (Goethe. F. 1957) As early as the fifth century A.D., ancient Greek art began to pay attention to the use of light in painting; in the Renaissance, the focus of Western painting gradually shifted from religious paintings to the depiction of secular life. Leonardo da Vinci proposed that the painter is the intermediary between nature and humanity, and he believed that the object can only be rendered through light and shadow. His theory of the gradual progression of light shadows will be linked to the picture of light shadows and color and the expression of light shadows' effects through different brightnesses of the same color. The theory of light shadow also influenced the religious paintings of the Renaissance. For example, the Ghent Altarpiece, which appeared in Belgium in the 15th century, used the difference in the brightness of the colors to express the effect of light shadow, with a

three-dimensional and realistic picture full of mysterious religious atmosphere. In the first half of the 14th to 19th centuries, color presented light shadow in this form.

Figure 19 The Ghent Altarpiece
Jan Van Eyck
(Source: The Ghent Altarpiece and
the Art of Jan van Eyck)

By the second half of the 19th century, the emergence of Impressionism made the relationship between light, shadow, and color reach a whole new level. At this time, artists were no longer confined to monochromatic brightness variations to express the effect of light and shadow but rather to express different light and shadow effects through various colors, which led to a close combination of light and shadow and color. (Betty. E.2004)For example, in Impressionist painter Monet's “The Rouen Cathedral series,” in different times of sunlight, the color of the building also changed; the same landscape in more than 20 works of color is different. In the period of modernism, colors began to express themselves in a separate way from the concrete. For example, Kandinsky, based on the contribution of color made by Impressionism and Symbolism and other factions, created an independent compendium of color itself. He analyzed the visual and psychological effects of different colors, making color almost entirely free from the bondage of concrete objects and further abstracted and purified.

Figure 20 The Rouen Cathedral Monet
(Source: Claude Monet: Life and Work）

In Western art, color variations are vibrant. During the Renaissance, Leonardo da Vinci proposed the theory of aerial perspective, and Western painting became increasingly varied and layered in the gradation of monochromatic shades. For example, in Leonardo da Vinci's "Woman Holding an Ermine," “ most of its colors are very richly varied in similar colors, and the occasional complementary colors are also reduced in purity and then softly appear in the picture.

Figure 21 Woman Holding an Ermine Leonardo da Vinci
(Source: Leonardo da Vinci: The Complete Paintings and Drawings)

By the time of Impressionism, color no longer expresses light and shade effects through monochromatic light and dark gradations, and polychromatic expression of light and shade impact makes the color changes in the picture more subtle. For example, in Van Gogh's 1889 work "Noon: Rest from Work (after Millet)," it can be seen that its color changes are very subtle, the color purity is low, but the brightness is high, and the picture as a whole is in a gray tone. The expression of color in modernist paintings appeared utterly different from the previous performance, such as the work of abstract painter Kandinsky; his work color seems to return to the original color concept, becoming more intense and pure.

Figure 22 Noon: Rest from Work (after Millet) Van Gogh (Source: Vincent van Gogh: The Complete Paintings)

Figure 23 Impression III (Konzert) Wassily Kandinsky (Source: Kandinsky: The Complete Paintings)

Summary

Color is essential in the real figurative world and works of art. The development of the standard color system is scientific, systematic, and equally versatile. Favre. J.P. expressed in “Color and Communication” that color can help people distinguish things and convey information through vision in the figurative world. Color helps artists show artwork better and helps viewers understand artwork better through color. Based on practicality, color itself has also formed a complete system. The formation of the standard color system has laid a solid foundation and strong theoretical support for the development of color so that color can be separated from the boundaries of figurative objects and develop more new possibilities.

2.3 Mural Paintings of Color from Other Areas along the Silk Road

Toshio Nagahiro, in the article "Cave Temples in China," states that Buddhist caves began to be built in India in the 2nd century B.C. As the Silk Road grew, Buddhism crossed the Hindu Kush into Central Asia and was introduced to China in the 1st and 2nd centuries A.D. It can be said that the brilliant civilization of Dunhuang Mogao Caves and the development of other cave murals on the Silk Road are inseparable, and because of the historical inheritance and the natural environment, the color of cave mural paintings on the Silk Road also has many similarities. Therefore, in this chapter, the Silk Road along the region: the critical area of the Southern Silk Road, the origin of Buddhist mural paintings of the Indian Caves, and Dunhuang adjacent to the Xinjiang region of the Caves, the natural environment of the Central Asian region similar to the Caves, the three regions as the main object of analysis, to explore the form and color characteristics of its mural paintings.

2.3.1 Indian Mural Paintings

According to Roy C. Craven's “A Brief History of Indian Art,” Buddhism originated in India, and Buddhist caves flourished in India before the 8th century A.D. However, because Buddhism declined earlier in India, most of the caves in India were created before the 8th and 9th centuries A.D. Because of its tropical monsoon climate, most of the caves in India are damaged and falling off. The only Indian cave that still has mural paintings is the Ajanta Caves, located in northeastern Mumbai. Opened

around the 2nd century B.C., the Ajanta Caves are India's most complete surviving caves with mural paintings.

Figure 24 Exterior of Ajanta Caves
(Source: Silk Road World Heritage)

The mural paintings in the Ajanta Caves are divided into two main periods: the Hinayana period and the Mahayana period. The Sātavāhanas Dynasty before the 1st century A.D. was a period of Hinayana Buddhism and was dominated by five caves, including Cave 8, Cave 9, and Cave 12. The other caves are from the Mahayana Buddhist period, which lasted from the Vākātaka dynasty from the 5th to the 7th centuries A.D. The Vākātaka Dynasty was married to the Gupta Dynasty. The Vākātaka art is often categorized as Gupta art, and the Ajanta caves are considered the culmination of the Gupta period of Indian art.

The Chaitya Cave dominates the caves of the Hinayana period. The central tower pillar caves in Dunhuang and Xinjiang are derived from the Chaitya caves, which belonged to the Buddha-less period. Therefore, the mural paintings are mainly Jātaka stories paintings. The caves of the Mahayana period are primarily a composite of the monk's house caves, with mural paintings on the surrounding walls, domes, and even on the front porch and the roof of the front porch, which are relatively well preserved. (Xu. H. 2002) The content of the frescoes is mainly the Jātaka life stories paintings and the Buddha's stories pictures. There is no interval between the mural paintings,

presenting a serialized narrative that vividly recreates the court life of the Gupta Dynasty in the 5th century, which is rich in content.

Because of the era's limitations, the pigments used in Indian cave murals are also very limited, similar to Dunhuang, which usually extracts colors from nature, mainly mineral pigments. (See 2.1.3 here.) However, the coloring technique was more developed, featuring Hinduka's shading and highlighting techniques (see 2.1.4 for a more detailed description), and was the source of the coloring techniques used in all the cave murals along the Silk Road.

As a result, the colors in the murals of the Ajanta Caves are rich in variations and layers. For example, the color transitions in the body of the figure of the Sage Jātaka stories picture in Cave 2, which was painted at the end of the 5th century A.D., are very delicate, with a strong sense of three-dimensionality, and rich variations in the layers, （Zhu.H.2002） which demonstrates the use of the Shading and Highlighting Techniques of Hinduka and the effects of the color modulation, which is even more refined compared with that of the murals of the Mogao Caves of Dunhuang of the same period (the Sui Dynasty).

Figure 25 Cave2 The Sage Jātaka stories picture
(Source: Ajanta: The Paintings of the Buddhist Caves)

The main surviving caves in India are the Ajanta Caves, Ellora Caves, and Elephant Island Caves. Except for the Ajanta Caves, none of the other caves have surviving frescoes. Therefore, the Ajanta Cave mural paintings allow us to explore the origins and

development of color expression in the Silk Road cave mural paintings and see the use of color in the cave mural paintings of ancient India. We can also see its similarity with the cave murals of other regions along the Silk Road.

2.3.2 Xinjiang Mural Paintings

Xinjiang is the most extensive region in China, and in ancient times, it was divided into several states. Caves in the Xinjiang region were first built around the 3rd century A.D. The present-day cave sites are mainly located in three regions: the ancient Kucina Kingdom (present-day Baycheng-Kuqa area), the ancient Gaochang Kingdom (present-day Turpan neighborhood), and the ancient Yanqi Kingdom (present-day Yanqi area). All three regions were significant on the ancient Silk Road and belonged to the Western Region of 36 Kingdoms. According to Chang Shuhong's “Xinjiang Cave Art,“ There are nine main caves in the Kucina Caves group, including the Kizil Caves, the Kumtura Caves, the Senmusem Caves, the Kizilgaha Caves, the Aai Caves, and other caves. The main caves in the Gaochang Caves group are the Tuyugou Thousand Buddha Caves and the Berziklik Caves. Yanqi area has survived the Qigexing Caves. The Kucina Caves group is the largest and most complete caves, with statues and mural paintings remaining in Xinjiang. Therefore, this chapter takes the Kucina Caves group as the main object of analysis and briefly analyzes the Gaochang and Yanqi Cave groups.

According to the “Biography of Emperor Mu of the Zhou Dynasty,“ the ancient Kucina Kingdom existed around 1,000 B.C. The words of Ban Gu, "The Book of Han,” recorded that the people of Kucina were good at music and rhythm and had a well-developed iron smelting industry; it was one of the most powerful countries in the Western Regions. The Kucina Caves group was first excavated at the end of the 3rd and 4th centuries A.D., with more than 600 existing caves and nearly 20,000 square meters of mural paintings. The style and content of the caves are similar, with long-term and stable regional ethnic characteristics (Zhao.L.2008). The Kizil Caves are the royal caves of the Kucina Kingdom, which are the most rich in content and the most well-known.

Figure 26 Exterior of Kizil Caves
(Source: Kizil Academy)

The cave formations of the Kucina Caves are available: The central tower pillar cave, the prominent Buddhist Cave, the monk's house Cave, the Square Cave, the Niche, and others. The central tower pillar is from India and is an ancient form. The monk's house cave in the Ajanta Caves also appeared, and other forms of Indian caves, such as Dunhuang's caves, emerged. The content of the mural paintings is mainly about Hinayana Buddhism, and there are Buddha preaching paintings, Nirvana paintings, Jātaka stories paintings, Karma stories paintings, and others.

Figure 27 Kizil Caves The central tower pillar
(Source: Kizil Academy)

The book "Mural Painting in Xinjiang, China: Kucina" argues that the Kucina Caves have undergone three stylistic periods: the Kucina, Han, and Uighur. Kucina style

refers to the local traditional culture, which is based on absorbing foreign factors and gradually producing and developing the style of Buddhist art. For example, the diamond lattice composition in the murals of the Kizil Caves and the use of intricate brush strokes named the "Qutiepansi"（屈铁盘丝） technique are the signature features of the Kucina style. Han style refers to the clear Han Buddhist art style in the Central Plains, formed by the strong influence of the Central Plains Buddhist art, with Mahayana Buddhism as the main content. For example, the emergence of The sutra paintings, the dome painting of a thousand Buddhas, and the emergence of Han-style Buddha Preaching paintings are notable features of the Han style. The Aai Caves in the Kucina Caves group are typical Han-style caves, and the Kumutula Caves also have Han-style caves. The Uighur style refers to 840 A.D. when the Kucina region was once under the control of the Uighur. The Uighur has been affected by the Han culture, so the Uighur style is based on the Han style, a combination of the Kucina regional culture and the Uighur aesthetic art style. The distinctive features of the migratory style are the use of colorful stripes and flames and portraits of providers for the three kinds of characters of the Kucina, the Han, and the Uighur. Portraits of providers for the inscription of the Kucina, the Han, and the Uighur are three kinds of text that are a distinctive feature of the Uighur style. (Zhao.L.2008)

The coloring techniques in the mural paintings of the Kucina Caves were still based on the Shading and Highlighting Techniques of Hinduka, and the halo dyeing technique was gradually used after being influenced by the Han style. (For details, see 2.1.4.) (Zhou.Z.B.2020) The Kucina style prevailed from the middle of the 4th century to the end of the 5th century A.D. The colors of the murals in this period were still in the stage of imitating and learning Indian painting techniques, and the colors overlapped dyeing and flat dyeing techniques. For example, Cave 38 of the Kizil Caves, excavated in the 4th century A.D., is dominated by blue and green, with simple coloring techniques and a strong Western Region style. Han style prevailed from the 7th century to the 8th century A.D., and Han refinements of the Shading and Highlighting Techniques of Hinduka influenced mural paintings of this period. Halo dyeing techniques appeared in Han-style caves, such as Cave 11 and Cave 30 in the Kumutura Caves. The mural color style and the same period of Mogao Caves color style are similar to the color layers of

color change, delicate and elegant. The Uighur style period in the 9th century A.D, although this period of the Kucina Caves tended to decline, the influence of Uighur culture gave the Kucina Cave mural paintings the color a new look. For example, the Uighur period of mural paintings often used warm red. In terms of coloring techniques, overlap dyeing, halo dyeing, and flat dyeing techniques are all three, and the style characteristics are very significant.

The ancient Gaochang area was under Dunhuang County in the early 4th century A.D. The book "Great Tang Records on the Western Regions" records that the ancient Gaochang Kingdom was a Han Chinese regime centered in the Turpan Basin. The Gaochang Caves group was first excavated in the 5th or 6th century A.D. and abandoned in the 13th century. There are 83 caves in the Gaochang Caves, including more than 40 caves with mural paintings.

Figure 28 Kizil Caves The Flying Apsara Cave 38
(Source: Kizil Academy)

According to Xa Lidong's research in the article "Study on the Staging and Genealogy of Gaochang Caves," the cave formations of the Gaochang Caves group are of the types of The central tower pillar cave, the monk's house cave, the storage cave, and other types. The mural paintings are mainly divided into three periods: the Gaochang period in the 5th century A.D., the Tang dynasty rule in the 6th century A.D., and the Uighur period in the 10th century A.D. Gaochang Kingdom was founded in 460 A.D., The color style of the mural paintings during this period was influenced by

Western Liang period, and was similar to the style of the Mogao Caves mural paintings during the Northern Liang and Northern Wei periods. In 640 A.D., the Gaochang Dynasty destroyed the Tang Kingdom, which set up a governmental organization in the Gaochang area, which the Tang Dynasty governed. The color style of the mural paintings in this period is similar to the Han style of the Kucina Caves group, which is influenced by the color concept of traditional Chinese paintings. After the 10th century A.D., Gaochang was occupied by the Uighur, beginning the period of Uighur. This period of mural painting style and the Kucina caves group of Uighur style are similar. To sum up, the Gaochang caves group and the Kucina caves group mural color in the staging, technique, and style are very similar. Here, I would like to describe the process briefly.

The ancient Yanqi Kingdom was also one of the Western Region countries, first recorded in the "Han Book - Yanqi Kingdom Biography." The Yanqi Caves group is dominated by the Qigaxing Caves, which were excavated from the 7th to the 9th century, and there are 10 caves. The big Buddha Cave dominates the caves, and the Buddha Preaching paintings and the Jātaka stories pictures dominate the mural paintings in the caves. Yanqi Caves group mural paintings research data is still relatively small, and no research data on the color of the mural paintings have been found for the time being.

2.3.3 Other Central Asian Mural Paintings

From Xinjiang westward, The Silk Road reached the Mediterranean Sea through Afghanistan, Iran, Iraq, and Syria in Central Asia, eventually reaching Rome. Central Asia is also a region that significantly influences the art of caves along the Silk Road. As a result of the perennial wars in Central Asia, there are very few surviving caves; the surviving caves are dominated by the Bamiyan Caves in Afghanistan and the Karatepa Buddhist cave-style monastic site in Uzbekistan. Because of the lack of documentation on other caves, this chapter will use these two caves as an example to analyze the representation of color in cave mural paintings in Central Asia.

Bamiyan is strategically located about 200 kilometers west of Kabul in the heart of the Hindu Kush region. After the Sassanid Dynasty of the Persians replaced the Kushan Dynasty in the occupation of Afghanistan, the area of Bamiyan split into a small country,

an ancient trade crossroads, and a major center for spreading Buddhism. Bamiyan was an ancient trade crossroads and a major center for the spread of Buddhism. It was a significant hub on the Silk Road between India and China. (Yu.B.X. 2022) The Bamiyan Caves were established around the 4th century A.D. The cave group, which stretches for 1.5 kilometers on the south side of the Hindu Kush mountain cliffs, contains more than 750 caves, making it the most significant surviving Buddhist caves. (Mayu. I. & Shigeru.K. 2013)

The Bamiyan Caves are in the form of the set-double-roofed cave and dome-shaped cave. According to Shao Xuecheng's article "The Forgotten Silk Road - From the Bamiyan Buddhas to the Kucina Big Buddha Caves," the et-double-roofed is a form of building that imitates a wooden structure. This form also appeared in the Kizil Caves of the Kucina Cave group, with the difference that while the set-double-roofed of the Bamiyan Caves was painted with Buddha and grassy patterns, the set-double-roofed of the Kizil Caves had only a simple pattern. The dome-shaped cave is also very similar to the Kizil Caves in the 123 cave, 67 cave form.

Figure 30 Bamiyan Caves The Set-double-Roofed Cave
(Source: Structure, Design and Technique of the Bamiyan Buddhist Caves)

Figure 29 Bamiyan Caves The Dome-Shaped Cave and murals
(Source: Structure, Design and Technique of the Bamiyan Buddhist Caves)

Bamiyan Cave mural paintings are not well preserved, both because they were not adequately protected during the war and because of the seriousness of the thefts and cuts. The existing mural paintings of the Bamiyan Caves also have many similarities with those of the Kucina Caves group; for example, they have the same lattice mural paintings, and the clothing of the Buddha and Bodhisattvas are very similar. At the same time, the Bamiyan caves also show prominent characteristics of Gandhara art. However, the Dunhuang and Xinjiang caves were also influenced by Gandhara art, but the degree was far less than that of the Bamiyan caves. For example, at the top of the upper niche of the head of the East Buddha is the mural "The Driving Sun God," which depicts the

sun god guarding the Buddha. With the stone statue of Buddha as the theme, the sun god is a Greek form, unintentionally corroborating the scene of East and West living in cultural harmony. (Zhao.Z.2021)

Figure 31 The Driving Sun God
(Source: Structure, Design and Technique of the Bamiyan Buddhist Caves)

Bamiyan Caves' mural paintings of color and Xinjiang Caves and Dunhuang Caves were similar to the use of mineral pigments and coloring techniques from India. The only difference is that Afghanistan is rich in mineral resources and originates from the valuable blue pigment lapis lazuli. Therefore, the mineral pigments used in the Bamiyan Caves are more abundant, and the colors are purer, especially the use of blue is very much, (Zhen.Y.Y.2021), such as the "Blue Maitreya" mural painting. Similarly, blue pigment made of lapis lazuli was also used in large quantities in the Xinjiang caves

Figure 32 Blue Maitreya
(Source: Structure, Design and Technique of the Bamiyan Buddhist Caves)

group adjacent to Afghanistan, and there are traces of lapis lazuli used in the Dunhuang caves group.

The Bamiyan Caves were destroyed by bombing in 2001. At this time, only previous documentation can be analyzed. However, many scientists are currently working on restoring the Bamiyan Caves using imaging techniques, and more documentation on the subject may become available in the future.

According to the book Gandhara and China, the ruins of the Karatepa Buddhist cave-like monastery, located in the northwestern part of the ancient Tirmez city, were constructed around the 2nd century A.D. and were gradually abandoned between the 9th and 12th centuries A.D. Karatepa has a total of about 20 caves, mainly the monk's house caves. The caves contain statues and mural paintings. (Mark.Y. 2022) The surviving murals are mostly Buddha Preaching paintings and Portraits of Providers paintings, and the color scheme is different from that of the Bamiyan Caves, with red as the dominant color. This is similar to the mural painting style of the Mogao Caves in Dunhuang in the 4th century AD.

2.4 Literature analysis of "Color Image Scale"

"Color Image Scale" is a book by Shigenobu Kobayashi, a Japanese color researcher, that helps designers and art creators understand and use color through a combination of science and art. Widely used in design, architecture, fashion, and advertising, the book systematically explains the relationship between color, visual effects, and emotion.

Shigenobu Kobayashi is a renowned Japanese color theorist and founder of Nippon Color & Design Research Institute, NCD. He has a deep academic background in color psychology and design and is dedicated to studying the relationship between color and emotion.

The main idea of this book is to establish a systematic framework of the relationship between color and emotion in visual effects so that the use of color becomes more scientific and rational. It is divided into two parts:

The first part introduces the reader to the basic information about the Color Image Scale, the primary color tool in this book. The scale is based on three core axes:

Elegant vs Dynamic: Whether the color gives a sense of static elegance or active movement.

Warm vs Cool: Whether the color gives a feeling of warmth or coolness.

Soft vs Hard: The intensity of the color ranges from smooth and relaxing to intense and exciting.

The book's second part uses the Color Image Scale based on different colors. The scale in the book categorizes colors in a three-dimensional emotional framework and sets the appropriate color combinations for each emotion. Designers and artists can choose the proper colors based on the emotion or atmosphere they wish to convey. For example, choose orange or light pink to convey a warm, soft atmosphere. Suppose one wants to convey a calm, elegant feeling; a combination of blue and gray may be the right choice.

The color research in this book emphasizes how color, transmitted visually, affects people's emotional responses. His research reveals the psychological impact of color and helps designers consider aesthetics and the emotional impact of color in visual design. For example, red often conveys strength, passion, and excitement. Blue, on the other hand, usually conveys an atmosphere of calmness, serenity, and professionalism.

The research methods used in this book are investigative and experimental, based on many field investigations and psychological experiments, and collecting a large amount of audience feedback data. These data support his hypothesis on how color affects emotion and provide a theoretical basis for the Color Image Scale. At the same time, the book also uses the quantitative analysis of color, which creates a way of dealing with color with rational thinking by quantifying the emotional effects of color, which has significant application value in the design field, especially in effectively solving the problems of subjectivity and uncertainty in design.

It contributes, firstly, to the development of the Color Image Scale, which, through its three core dimensions, provides designers with an intuitive and practical tool for selecting appropriate colors in different design scenarios. This model offers a structured framework for understanding and analyzing the relationship between color and emotion. Second, the proposed theory of color-emotion association not only describes the aesthetic value of color from an artistic point of view but also examines the impact of color on emotion, behavior, and environmental perception from a psychological point

of view. Finally, the book also explores the differences in the perception of color in different cultures, such as the symbolic meaning of white in Western culture versus its other meaning in Eastern culture. This provides a valuable reference for designers when designing in the context of globalization.

Although the Color Image Scale provides a framework for the relationship between color and emotion, different audiences may not perceive and react to color similarly due to individual and cultural differences. Therefore, the theory's generalizability may be limited in other cultures and contexts.

Despite its limitations, the Color Image Scale is a landmark book in the study of color design and color psychology. Through systematic research and experimentation, Shigenobu Kobayashi has dramatically influenced the field of design and color psychology by proposing a theory of the association between color and emotion and providing a practical tool for the Color Image Scale.

This study will focus on formulating a color system for the Mogao Cave murals concerning the methodology used to develop the Color Image Scale in Color Image Scale.

2.5 The Intellectual Coloring System of Mogao Cave Mural Paintings in the Northern Dynasties and the Tang Dynasty: An Art Scholars' Perspective

Since the 20th century, studying the Mogao Caves at Dunhuang has gradually increased. In 1907, Marc Aurel Stein (1862-1943) and Paul Pelliot (1878-1945) took many scriptures and silk paintings from the Dunhuang Sutra Cave, which caused a great sensation then. Dunhuang gradually appeared in the vision of world scholars, and the study of Dunhuang gradually formed an independent discipline.

In the mid-20th century, Dunhuang was studied around the world. Japanese scholars studied it most extensively and systematically. The Japanese scholar Kiichiro Kanda stated in his book "Fifty Years of Dunhuang Studies" that "Dunhuang studies is a part of Central Asian studies, and it occupies a position of such significance in Central Asian studies that the name of Dunhuang studies is sometimes used in substitution for Central Asian studies. " These remarks on the broader and narrower meanings of Dunhuang studies elevated the status of Dunhuang studies to the realm of all of Asia. Thus, it was said then that "Dunhuang is in China, and Dunhuang studies are in Japan."

In 1944, China established the Dunhuang Research Institute in Dunhuang. Chinese scholars gradually began to pay attention to the study of Dunhuang, and the research center of Dunhuang studies gradually shifted to China. By the 21st century, Chinese scholars had achieved a lot in studying Dunhuang.

Through the study of various aspects of Dunhuang literature since the 20th century, it is concluded that the study of the color of Mogao Cave mural paintings in the Northern Dynasties and the Tang Dynasty is embodied in different aspects and involves a wide range of fields, but basically, it is mentioned in the study of other contents or analyze other content based on color., and systematic research has not yet been formed. Therefore, in this chapter, the research on the color of Mogao Cave mural paintings in the period of the Northern Dynasties and the Tang Dynasty since the 20th century will be organized and analyzed.

2.5.1 Research by Western art scholars

The earliest research on the color of Mogao Cave mural paintings from the Northern to Tang dynasties can be traced back to 1907, as indicated in the analysis of Tang dynasty mural paintings in Mogao Caves in"Stein's Account of Archaeology in the Western Regions" by Stein:

"All the principal deities, and the bodhisattvas who surrounded them, were dignified and composed in various forms, while the Indian forms, which had come from Central Asia, were still clear. Though infiltrated with Chinese flavor in painting and coloring techniques, the sacred practices displayed in Greek Buddhist art are still preserved in the faces, noses, and folds of the statues of Bodhisattvas and Venerable Ones."

This passage shows that in Stein's initial examination of the Mogao Caves, he discovered the characteristics of the color of the mural paintings. He believes the coloring technique imported from India and China's indigenous color characteristics are reflected in Greek Buddhist art, which refers to the Gandhara art of ancient India. This evaluation of the Mogao Cave mural paintings' color statement is more accurate, but also for the later Mogao Cave mural paintings' color research to clarify the general direction.

Paul Pelliot visited Dunhuang in 1907 and numbered and organized the Mogao Caves. In his book "Paul Pelliot's Notes on the Dunhuang Caves," he made several pioneering conclusions about the color of mural paintings in the Northern dynasties and the Tang dynasty:

First, he believes that the formation of "brownish purple" color changes in the mural paintings after weathering and oxidation over a long period is the main feature of an "ancient style." The formation of this "brownish-purple" depends on the proportion of colors used by the painters, and the brownish-purple color of the face is derived from the oxidation of the flesh color. According to Pelliot's statement, he believed that the color change after oxidation depended on the color proportion. Still, he did not further express the reason, so this statement is doubtful. Still, for the first time, the color proportion was considered a positive significance for the later study of mural painting color.

Secondly, he suggests that unoxidized but peeling and fading color expression is a characteristic of the "common style." This refers to many undisclosed, mainly red, green, and blue murals in the caves, such as most Tang dynasty mural paintings.

Thirdly, according to Pelliot, there is also a particular variation in the color of mural paintings in the same cave where there are multiple dynasties, "This color characteristic is formed because it is not painted at once, but rather many times and by the cross-section or longitudinal section of the wall of the cave. Thus, the color variations are produced." This statement proves Pelliot's point that there were multiple repainting of the Mogao Cave mural paintings and that the shedding of the later repainted mural paintings revealed earlier ones, which also caused a color change. This is a very inimitable point of view, and it has been proven to exist in later studies.

Fourth, Pelliot extracted a variety of color specimens from the Mogao Caves and recorded the style and area of use of each color. In the extracted color specimens, Pelliot also found the phenomenon of color overlap dyeing, for example, in his analysis of "brownish purple" and "rose":

"The rose color survived when it was somehow omitted to paint a layer of undoubtedly darker rose color (which led to the brownish-purple color that exists today) underneath that rose color. Alternatively, perhaps we should admit that both layers of rose color (the first and the second underneath) were independent and that the second

layer of color may have been a deposition of the only layer of color that altered the hue of the initial light white layer on the wall."

Although the expressions "brownish purple" and "rose" are inaccurate, according to modern technical analysis, these two colors should be caused by oxidation discoloration. However, they illustrate the method of overlap dyeing used in coloring the Mogao Cave mural paintings, which, as shown in 2.1.4, is derived from the Shading and Highlighting Techniques of Hinduka. The extraction of color specimens and the use of regional records for the later Mogao Cave mural paintings color study provide first-hand information. Still, unfortunately, he did not carry out a scientific analysis of the composition of the color. In the next section, this defect will be discussed later in the study of Chinese scholars after the details are completed.

The British sinologist Waley, who was part of Stein's team in organizing and compiling the Dunhuang literature, was also a representative of Dunhuang studies at the same time as Stein. In his book "Catalogue of Paintings Acquired by Marc Aurel Stein," he made a statement about the dating of murals through color:

"A further clue to a division of history into periods is the pigments they use. The 10th century employed an inferior quality and easily flaked blue, leaving only a dirtier and grayish residue. By 950-975 A.D., orange and yellow were popular. Blue had almost disappeared, and red, usually of the purplish Indian variety, never reached " cinnabar. "

This discussion is accurate. It explains that after the Tang Dynasty (907 A.D.), the decline of the Mogao Cave mural paintings in terms of color was also gradually revealed, indicating the gradual decline of the Silk Road. However, the "Indian kinds of red" in the article failed to provide further explanation, which is here in doubt.

Dunhuang studies gradually emerged in Japan at the beginning of the 20th century. Still, most of them were the collation and analysis of Dunhuang documents, and the study of the color of the mural paintings in the Mogao caves in the Northern Dynasties and the Tang Dynasty was seldom seen; only in 1987, Kazuo Yamazaki analyzed the connection in color between the cave murals in the various regions of the Western Region in his article "About the Color of the Western Region Mural Paintings." The article shows:

"Documentation and analysis of the use of pigments in mural paintings throughout the Western Regions was scarce in research at that time. Only slightly more detailed reports can be seen in the Bamiyan and Kizil mural painting reports."

This is a good indication that the study of the color of cave mural paintings has not yet formed a system in Japan either. The article also indicates that the blue and green pigments used in the murals of the Kucina Caves group and the Gaochang Caves group in Xinjiang are not the same and that most of the Kucina Caves group uses lapis lazuli and chlorocopperite ore, which is similar to that of the Afghanistan region. In contrast, the Gaochang Cave group is dominated by blue copper ore and malachite. This also thoroughly explains the Silk Road in the Western Region countries of the mural paintings of the caves in the color of the connection. Moreover, about the color study of Dunhuang mural paintings, Kazuo Yamazaki said:

"As far as the pigments of the Dunhuang mural paintings are concerned, no Chinese research has yet been known, and the only citation available is the unpublished part of Wahlner's work by Gates. None of these sources have been investigated or dated. The Poston Museum of Art collection, which dates from the 8th to 9th centuries, lists only eleven pigments in the table. The presence of cochineal, garcinia, and blue, and the absence of loess, which is supposed to have been used, are puzzling."

This shows that research on the color of the Mogao Caves in Dunhuang at that time was very scarce in China and the world. This was the only article published at that time on the study of the color of mural paintings in the caves along the Silk Road. It pointed out very clearly the status of mural color research in the 20th century. However, there was still no progress in studying the color of mural paintings in the Mogao caves in the Northern Dynasties and the Tang Dynasty.

Other Japanese studies on the color of the mural paintings in the Mogao caves in the Northern dynasties and the Tang dynasty are mostly combined with other elements. Usually, the color characteristics of the mural paintings are mentioned in the description of the mural paintings. For example, Nishibayashi Takahiro, in his article "New Development of Large-Scale The Sutra Paintings in the Late Early Tang Dynasty - Focus on the Mogao Cave 217 Mural Paintings at Dunhuang," describes the backlighting of the Buddha statues in the following terms:

" Most backlight representations of the Tang Dynasty are depicted with double or triple concentric circle-shaped contour lines, and even if opaque, they are not painted with only individual colors, but dark blue, cinnabar, and green are formed into concentric circles." Color is often briefly analyzed when describing the characteristics of the subject under study.

There are also cases where other content is analyzed through color patterns. For example, Kaoru SUEMORI, in "Formation of Buddhist Cave Spaces in the Northern Zhou Dynasty at Dunhuang Mogao Caves, China; Analysis through a directivity indicated by mural motifs, “in his study of the mural paintings of the Northern Zhou period at the Mogao Caves, has used the continuum of color to analyze the design ideas of cave mural paintings:

"Two different types, known as "crossovers," were used for the east, north, and west walls. The east, west, and north walls have the same slant and the same color scheme for the head and body, but there is no continuity in the color scheme between the east and north walls and between the west and north walls, where the four bodies are in pairs. This shows that although the Yongsei Thousand Buddhas of Cave 428 were designed with continuity in the diagonal direction of the four walls, there is little awareness of the need to show continuity across the walls. This contrasts the characteristics of the Thousand Buddha Cave in Cave 290, where the diagonal orientation and color scheme are continuous throughout the walls."

By analyzing the pattern of the color arrangement of the Thousand Buddhas in Cave 428, we can explore the characteristics of the mural painting layout of the cave and the thinking of the mural painting creators. This is also the positive role played by studying the color of mural painting in Dunhuang studies.

Color analysis of the Mogao Cave mural paintings from the Northern Dynasties to the Tang Dynasty can be used in addition to artistic aesthetic studies and is usually used to analyze the oxidation of the mural paintings.

In "Influence of Light Environment on Deterioration of Mural Paintings in Mogao Cave 285, Dunhuang," Daisuke Ogura et al.: “The influence of the hygrothermal and light environments on the deterioration of mural paintings in cave 285 was examined via several experiments using simulated mural paintings.” This article analyzes the stability and shedding of each color in Cave 285 during the Western Wei period very

precisely through experiments, which is very important for the study of the color of Mogao Cave mural paintings, as well as briefly analyzes the color composition of the mural paintings, but some points remain inaccurate. For example, in this article, it is argued that "the main ingredients of white color are Talc, paragonite: silicon and magnesium." in the analysis of 2.1.3, it is found that the primary sources of white color, calcite, and kaolinite, do not contain Talc and other substance., and this should be questioned.

In addition, Akane Mikayama et al., in “Effects of drifting sand particles on the deterioration of mural paintings on the east wall of cave 285 in Mogao caves, Dunhuang," analyzed the effect of sand on the cracking of mural paintings' coloring layer through experiments, and indirectly analyzed the coloring from the geological perspective.

The above analysis of foreign research related to the color of mural paintings in the Mogao Caves in the Northern Dynasties and the Tang Dynasty shows that color research is not mature enough and perfect. The color of mural paintings is a scarce central research aspect of the literature. The study and analysis of Chinese scholars will supplement this point.

2.5.2 Research by Chinese art scholars

The study of Dunhuang in China began to develop in the mid-20th century. In the early days, it was limited to conserving cultural relics and copying murals. The famous Chinese artist Zhang Daqian spent three years copying murals at Dunhuang, and Dunhuang gradually received more attention. By the end of the 20th century, many systematic Dunhuang literature and monographs had been published, and the center of Dunhuang studies gradually shifted to China.

Among them, Li Yadong published an article entitled "The Study of Dunhuang Mural Pigments" in 1983, the first time pigments were studied separately. Wan Gengyu first analyzed the color dyeing techniques of Mogao Cave murals in his paper "One of the Techniques of Dunhuang Mural Paintings--Halo Dyeing," published in 1985, affirmed the relationship between the colors of Mogao Cave murals and the techniques of Hinduka paintings, and put forward the concepts of "Shading and Highlighting Techniques of Hinduka,” "Overlap Dyeing Techniques" and "Halo Dyeing Techniques"

and briefly explained them. This article on the Mogao Cave mural paintings' coloring techniques of the vein combed very clearly, but it only made a general statement and did not analyze it individually.

In 1990, Zhou Dazheng published an article entitled "Analysis of the Concept of Color in Dunhuang Mural Paintings," which expressed the reasons why the color of Mogao Cave mural paintings was not taken seriously by researchers from the perspective of art criticism:

"Color has been doubly neglected as an aspect of traditional culture. It seems to be treated as a weak point in the theory and practice of traditional painting, and there has long existed a conceptual inclination to belittle and downplay color. Color a few pings seen as non-traditional foreign goods, The field of "Western" and "Oil Painting." Conceptually excluded from the traditional authenticity, satisfied with the traditional advantages of the brushstroke（笔墨）techniques, formed a set of traditional concepts of "emphasizing brushstrokes over color" and seemed to be confined within the scope of brushstrokes and charm in the theory of technique."

This passage fully demonstrates that the color of Mogao Cave mural paintings has been a low priority for a long time. Zhou Dazheng believes this is related to the weakening of color in the development of Chinese paintings. Still, through the analysis in 2.4.1, foreign scholars have also neglected the color of Mogao Cave mural paintings, So the notion of weakening color in Chinese painting may be only one of the reasons. There are other reasons to be analyzed.

Since 1995, X-rays have been used in the field of Dunhuang research. Wang Jinyu, Su Bomin, and others have analyzed the colors of the Mogao Caves one by one through X-rays in terms of their composition and published many papers such as " Study of Blue Pigments Unearthed from the Mogao Caves of Dunhuang," "Study on the Stability of Mixed Red Pigments in Dunhuang Mural Paintings," and "The Application and Sources of Copper-Green Pigments in Dunhuang Caves." Among them, Su Bomin believes:

"Mural paintings pigment discoloration and fading seriously affects the artistic effect of the mural paintings content. Therefore, cultural relics conservation researchers attach great importance to studying the causes of pigment discoloration and fading and the stability of the pigment itself. The discoloration and fading of pigments is also a major problem in the conservation of mural paintings."

This shows that the analysis of pigments has been given more importance in archaeological research. However, these documents are the source of color and pigment composition of critical data; since then, the study of Mogao Cave mural paintings' color has added new vitality. Thus, the Mogao Cave mural paintings' color is neglected not only the traditional "neglect color" concept factors but also technical support reasons. However, since then, the analysis of pigment composition has not received more attention from art researchers and has been used more in geological archaeology, which is a major regrettable in studying the color of Mogao Cave mural paintings.

In the "Dictionary of Dunhuang Studies" published in 1998, the color aspect of the mural paintings is only summarized in 16 separate entries, such as “Apply color, Fill color, Shading and Highlighting Techniques of Hinduka, Overlap and Halo dyeing,” which were written by Li Qi-Qiong and placed in the chapter of "Mural Techniques,” where other aspects such as pigment and color application are not mentioned. This is the earliest monograph that briefly explains and analyzes the techniques of mural painting color and provides an outline for the later study of mural painting color in the Mogao Caves. In the book "General Catalogue of Dunhuang Studies in China,” published in 2010, the study of color is mainly placed in the chapter "Protection of Cultural Relics."

This shows that in the 20th century, Chinese researchers on the color of Mogao Cave mural paintings, color techniques, pigment analysis, color concepts, and other aspects were placed in different areas for study and did not treat the color of Mogao Cave mural paintings as a complete field.

At the beginning of the 21st century, researchers focused on the color study of Mogao Cave mural paintings on dyeing techniques, the study of color characteristics, and the analysis of color in different dynasties.

For example, Ma Yuhua's "Techniques and Color Composition of Dunhuang Mural Paintings in the Northern Liang and Northern Wei Periods," Li Zuixiong's "An Analytical Study of Painting Pigments of the Tang Dynasty in the Mogao Caves of Dunhuang," and Xu Yong's "A Study of Pigments Used in Dunhuang Area in the Late Tang and Fifth Dynasties," and other articles have been categorized and studied with the qualification of dynasties, and have examined the different aspects of the color of the mural paintings in the Mogao Caves in the Northern Dynasties and the Tang Dynasty.

Regarding dyeing techniques, the Shading and Highlighting Techniques of Hinduka have been discussed many times and have generated much controversy. For example, in the Dictionary of Dunhuang Studies and previous studies, the Shading and Highlighting Techniques of Hinduka were considered to be the " Tianzhu Method"(天竺遗法) mentioned by Xu Song of the Tang Dynasty in the “Jiankang Records,“ and this definition was accepted by later studies, However, in Gu Ying's 2000 article "On the Three-Dimensional Method and the Inherited Tianzhu Method of the Western Regions,” which distinguishes the Shading and Highlighting Techniques of Hinduka from the Tianzhu Method, Gu Ying argues:

"Shading and Highlighting Techniques of Hinduka is one of the most basic techniques of western Region style Buddhist paintings; although it is based on the ancient Indian method of halo dyeing, at the same time, it is also developed based on a combination of other cultural factors, and its techniques, programs, and effects are significantly different from the so-called "Tianzhu method.” Therefore, in the study of “ Western Region Paintings," A distinction should be made between "Tianzhu Method" and Western Region style "Shading and Highlighting Techniques of Hinduka" to more clearly grasp the style and characteristics of Western Region style Buddhist paintings."

This view defines the Tianzhu Method and the Shading and Highlighting Techniques of Hinduka separately, which is different from other researchers. However, the accuracy and practical application have not been verified, so this view is still doubtful.

Meanwhile, Duanan, in an article published in 2019, “Review on the Shading and Highlighting Techniques of Hinduka,” “ through the traceability of Indian painting techniques, the translation of ancient Indian Sanskrit literature, and the comparison with the color techniques of the Mogao Cave mural paintings and other aspects, the Shading and Highlighting Techniques of Hinduka are explained and analyzed in all their aspects, according to Duan Nan:

"The Shading and Highlighting Techniques of Hinduka, also known as the " Tianzhu Method,” refers to the coloring methods used in ancient Indian paintings. Although the name "Shading and Highlighting Techniques of Hinduka" is taken from the Chinese language, it refers to the painting techniques of ancient India, specifically to the dyeing method in the stage of "using colors,” which is the flexible use of light and

dark colors, deep and light colors, and various fine dyeing strokes. These methods entered the Xinjiang and Gansu regions of China with the spread of Buddhism and were widely used and newly developed in the murals of the Kizil and Mogao caves; when they were introduced to the Central Plains in the Northern and Southern Dynasties, the Sui and Tang dynasties, they were improved by the painters of the Central Plains, and then presented a different feature."

This paragraph shows that Duan Nan believed that the Shading and Highlighting Techniques of Hinduka and the Tianzhu Method were the same painting technique. In her article, Duan Nan compares the explanations of Shading and Highlighting Techniques of Hinduka in ancient Chinese literature with those in ancient Indian literature, proving that the two are homologous. Moreover, derived three new coloring techniques from ancient Indian literature--"tisraśca vartanāh prokāh patrācchaidikabindujāh," and through examples to prove that these three color techniques have appeared in the Mogao Cave mural paintings and Kizil Cave mural paintings. Duan Nan's research results are a breakthrough in the Mogao Caves mural paintings' color techniques; the shading and Highlighting Techniques of Hinduka have a clear source and definition, and the Mogao Caves mural paintings' color technique research is more mature and complete.

With the continuous development of science and technology, the research on Mogao Cave Mural Paintings Pigment is also developing gradually. In the article "Research Process of Dunhuang Mogao Cave Mural Painting Pigments and Detection Techniques," published in 2022, Su Bomin summarized and perfected the previous research and explained the new technology. "FTIR," "Raman," and "LIBS" and analyzed the composition of organic pigments in Mogao Cave mural paintings using the latest techniques. Su Bomin believes:

"In the future, we need to conduct in-depth research on interpreting the mechanism of pigment discoloration and identifying some organic materials. By introducing more accurate analytical methods and technical means, we will reveal the source of Dunhuang mural pigments and their deterioration process more systematically. Further clarify the era characteristics of Dunhuang mural painting materials and painting techniques, clarify its development, and continuously enrich and improve the knowledge system of Dunhuang mural painting materials and painting techniques."

This suggests that there are more possibilities for research on pigments in the future and emphasizes the relationship between pigments and technique. The study of mural painting color in China must shift from the previous categorical study to a gradual trend of merging.

Unlike the traditional research content, research on the digitization of Mogao Cave colors has gradually emerged in the past two years. "The development and application of a multispectral digital identification system for Mogao Cave mural paintings pigments," by Chai Bolong et al.:

"The research and development of the pigment multispectral digital identification system initially realized the purpose of automatically identifying a single pigment category in a multispectral image through software, which solved the errors in the analysis process that used to rely on visual recognition., weakened the difficulty of identification, and improved the efficiency and accuracy of analysis."

In this article, the author extracted 24 colors by experiment, which shows that the colors of mural paintings can be accurately extracted by relying on modern technology. However, the method mentioned in this article has not been correctly applied, is more concerned by researchers of cultural relics conservation, and has not been given enough attention in art.

Similarly, Liang Jinxing et al. proposed "a method for constructing a color database of Dunhuang mural paintings" in "A method for constructing a color database of Dunhuang mural paintings." According to Liang Jinxing et al:

"Firstly, a basic color scale system for Dunhuang mural paintings will be established, and the spectra, colors, particles, and material properties of each pigment color sample in the color scale system will be quantitatively calibrated to establish a basic database for the color scale system of Dunhuang mural paintings; Then combined with the research results of the "Digital Dunhuang" project, the image data of the digitized caves were cataloged in fine zones, and non-contact non-destructive measurement and calibration were carried out for each fine zone to obtain the color, physical and chemical properties of the data of each fine zone; finally, the mapping relationship between each fine zone and the color samples of the basic database of the color scale system of the mural paintings at Dunhuang was established, completing the construction of the Dunhuang mural paintings pigment color data."

The article analyzes the feasible type of this method; combined with the article "The development and application of a multispectral digital identification system for Mogao Cave mural paintings pigments, “The basic color scale system has not been established, so the creation of a pigment color database is currently tricky. However, the ideas provided in this article may be applied to more Mogao Cave color research and practice in the future.

To summarize, comparing the research of foreign Dunhuang studies, Chinese Dunhuang studies in the last 70 years have advanced by leaps and bounds, producing a large amount of literature and information. The survey of mural paintings color in the Northern dynasties and the Tang Dynasty is also reflected in articles in different fields, which is similar to that of foreign research, except that the Chinese research results are more numerous and broader in scope, which has a great deal to do with the importance that China attaches to Dunhuang studies, the ease of obtaining first-hand information, and the enthusiasm of scholars for Dunhuang studies.

Regarding the study of color in mural paintings in the Northern Dynasties and the Tang Dynasty, China and foreign countries have not been able to form a complete system after all. Different aspects of color are discussed in various fields; for example, color technique is usually analyzed in painting technique, and pigment analysis is generally studied in archaeology and conservation of cultural relics. Therefore, exploring color as a separate object for the mural paintings of the Mogao caves from the Northern to the Tang dynasties is essential. In the next section, this dissertation will discuss how to study the following: refer to the other color system, analyze the Mogao Cave murals in the Northern Dynasties and the Tang Dynasty by comparing the color performance and characteristics of the cave murals in different regions along the Silk Road, to make the study of the color of the murals form a more complete and comprehensive system.

2.5.3 Studies on Color in Caves Mural Paintings in Other Regions Along the Silk Road

2.3 outlined the current state of the caves along the Silk Road, and color has been relatively little studied in these caves. This subsection will continue the framework of

2.3 by extracting and analyzing color studies in Indian caves, Xinjiang caves, and other Central Asian caves.

First of all, in the existing literature on Indian cave mural paintings, there is very little research on color. The concept of color in ancient Indian mural paintings can be seen in the Citrasūtra, which was written from the 6th to the 10th centuries A.D. Their coloring process is recorded in Chapter 40, Rangavyatikara, of the “Citrasūtra”:

"The artist should draw the proportions and poses in the drawing.

Afterward, apply a variety of colors as outlined.

It should show the shades of skin color the portrait should have."

This is the method of applying the Shading and Highlighting Techniques of Hinduka. Although the available written records are dated to the 6th century A.D., based on the color representations of the early murals from the Hinayana period in the Ajanta Caves and other caves along the Silk Road, the Shading and Highlighting Techniques of Hinduka were widely utilized in India at a very early stage and spread to other regions.

The “Citrasūtra” also records about the modulation of colors:

The five traditional fundamental colors are white, yellow, red, blue, and black.

My King, there are hundreds of other colors.

By mixing the previous colors according to emotion and imagination,

one can make hundreds of colors with one's ingenuity.

It is said that blue and yellow are mixed to make green.

A color is either pure or mixed.

Add black or white, as the case may be.

All fall under the category of mixed colors.

There are three ways to add more white, less, or equal amounts.

There are many different kinds of color mixing, using one color as the primary color.

It is a beautiful color.

There is the soft green of the lucky grass buds.

The yellowish green of the wood apple.

My king, these dominant colors (green) are obtained from dark green beans.

When dark blue is mixed with white, the color fades.

There are also many ways to obtain different colors, such as increasing, decreasing, or equalizing each other.

This results in a blue color like a green lotus flower and a bright gray-blue color like a bluebird.

(This chapter was translated from Sanskrit by Dan Nan.)

This passage shows that the concept of primary colors was also present in the painting of Indian mural paintings, where white, yellow, red, blue, and black were considered primary colors, and hundreds of colors were derived by mixing these five colors. Similarly, India was ahead of the rest of its contemporaries in the perception of color, and they distinguished early on between pure and mixed colors, or what is known in color science as orthochromatic and interchromatic colors. A series of shades of one hue are classified as mixed colors. One color is chosen as the primary color, and adding white improves the brightness, lightens the color, and results in various colors due to the difference in the amount of additions. This coincides with the familiar concept of color, and Dunhuang Mogao Cave mural paintings in the color performance do not show this feature, which shows that the Indian painting techniques in the process of spreading through the Silk Road, as a result of the different regional cultures, has also undergone some changes.

Xinjiang Caves mural paintings contain more color-related information than Indian mural paintings. In the study of the Kizil caves in the Kucina Caves group, the contemporary scholars' research results are more, less ancient primary sources. In modern scholars' research, the study of pigments is dominated. Compared with the Dunhuang Cave group study, the research results are relatively single.

The Kucina Cave mural paintings are similar to the Mogao Cave paintings using pigments (see 2.1.3), but some differences remain. First, in the use of blue pigment, the blue pigment of Mogao Cave murals is dominated by blue copper ore ($Cu_3(CO_3)_2(OH)_2$) and lapis lazuli ($Na_3Ca(Al_3Si_3O_{12})S$), according to Su. Bomin et al.'s analysis of the nature of blue pigments in the murals of the Kizil Caves in the article "Study of Pigments in the Murals of the Kizil Caves" written in 1999, the blue pigments used in the Kucina Caves Group were mainly lapis lazuli. Su.B.M. et al. stated:

"All of the blue pigments analyzed were lapis lazuli, and there was no staurolite, another blue pigment found in Dunhuang mural paintings. This is another feature of the use of pigments in the Kizil caves. The results of the literature show that there is no lapis lazuli origin in China, and the lapis lazuli pigment used in Dunhuang mural paintings is likely to come from Afghanistan, where lapis lazuli originates more. We use a polarized light microscope to compare the lapis lazuli pigment used in the Kizil caves with the lapis lazuli specimens from Afghanistan. The two have extremely similar particle morphology and accompanying mineral characteristics. Since Dunhuang and the Kizil Caves were two famous trade hubs on the ancient Silk Road, and the mural paintings of the two places have a close inheritance relationship, based on the above reasons, we can initially recognize that the lapis lazuli of the mural paintings of the Kizil Caves originated from the Afghan region."

This discovery fully demonstrates that the pigments used in the mural paintings of the caves along the Silk Road all have similar characteristics, further proving the connection between the caves along the Silk Road.

Secondly, Zhou Zhibo found in his research that garcinia is used in the murals of the Kizil Caves, which is different from the use of inorganic pigments such as loess, realgar, and orpiment from the gold stone in the mural paintings of the other caves. Orpiment is an organic pigment, and there is no garcinia in the Mogao Caves. This discovery has a positive role in studying pigment types in mural painting.

Third, the white color in the murals of the Kucina Caves mainly uses gypsum (CaSo4), which differs from that of the Mogao Caves. This is illustrated in the article "Research on the pigments of the murals of the Kizil Caves ":

"From the results of x diffraction and polarizing microscope analysis, it is concluded that the white pigments of the Kizil Caves are mainly dominated by gypsum, while calcite and quartz are the impurity minerals contained in the gypsum. Microscopic observation of pigment flakes and pigment profiles shows that gypsum was mainly used for white ground pigments and color matching with other pigments."

This finding is different from the theory "White color is produced by calcite, kaolinite, etc." in Su BoMin.'s paper "The Research Process of Dunhuang Mogao Cave Mural Painting Pigments and Detection Techniques," published in 2022. This suggests

that the use of white color in the Kucina Caves group is different from that in the Mogao Caves.

Fourthly, gray pigment was found in the murals of the Kucina Caves, and Zhou Zhibo argued in his 2020 article "Research on the pigments of the murals of the Kizil Caves" that this gray color was a mixture of black and gypsum. In Summary, the pigments used in the murals of the Kucina Caves are rarer and more valuable than those of the Mogao Caves; however, the pigments are the same in terms of their origin.

The existing research does not include studies on the color of mural paintings in the Gaochang Cave Group and the Yanqi Cave Group. The other Central Asian caves are not discussed here because there is even less research on them, and no research on color is found in the existing literature.

2.6 A Study of the Distribution of Color Use in Mural Paintings

The study of the color use area in mural paintings is essential in the study of mural painting color. From the color use area, we get the color tendency of the mural painting picture, the picture tone, warm and cold, and the inner meaning of the color use. We can also prove the rarity of the pigment side by side. This is an essential part of formulating the color system of the Mogao Caves mural paintings and will play a key role in the process of the color system being used.

Among the existing studies, there are very few on the use of color areas in Mogao Cave mural paintings, only mentioned by Su Bomin in his 2022 article "The Research Process of Dunhuang Mogao Cave Mural Painting Pigments and Detection Techniques":

"Red: In the color composition of Dunhuang Mogao Caves mural paintings, red is a prevalent color; the character's lips, robe, and many other positions are used in red.

Blue: Besides red, another pigment used extensively in Dunhuang mural paintings is blue.

Black: black pigment is commonly used in Dunhuang mural paintings to outline figures, buildings, etc., and its composition is dominated by carbon black (amorphous carbon)."

As shown in the above statement, Su Bomin only discussed in an overview way whether different colors are standard in Mogao Cave mural paintings and in which positions they are usually used, which is far from enough in the study of color use.

On the other hand, the study of color use areas in other caves is only a part of pigment study or color sampling, and there is no separate and specific combing and research process. The relevant literature that can be found at present are two articles about the color study of the Kizil Caves, in the paper "Research on the pigments of the murals of the Kizil Caves" published by Zhou Zhibo in the Journal of Zhejiang University, the pigments in Cave 69 of the Kizil Caves were sampled, during the sampling process, the position of the different colors in the mural paintings was recorded and the percentage of each element in the different pigments was tabulated. On the collection of samples, it is stated in "Research on the pigments of the murals of the Kizil Caves":

"In 2013, during the implementation of the salvage conservation and restoration project for the mural paintings in Cave 69 of the Kizil Caves, fragments of mural pigment that had been detached and could not be reattached were collected as samples, It was used to study the materials used to make the mural paintings in the cave and the production process. 14 samples were collected in five colors: blue, green, red, white and gray."

A list of sample information and the atomic percentage of each element in the sample is displayed, for example:

Table 2 Zhou, Z. B. on the Kizil Cave Color Distribution Location

Serial No.	Sample No.	Collecting Location	Possible dislodgement location	Appearance Description
1	69B-1	In front of the statue of Buddha on the left wall	The blue part of Buddha's hair bun	Blue flake pigment

Table 3 Zhou, Z. B. on the Kizil Cave Pigment Ingredient Analysis

Serial No	Na	Mg	Al	Si	S	Ca	Cl	Pb	As	Fe	Cu	P
69-1	14.30	2.43	24.69	42.15	11.17	2.54				2.72		

Two blue pigments, two green pigments, six red pigments, two white pigments, and two gray pigments were extracted from the above two tables. It is clear from the above information that in the mural paintings of Cave 69 of Kizil Cave, blue is usually used in the dyeing of the hair bun of the Buddha statue, green and grey are often used in the skirt and the backlight, red is used a lot in the position of the robe and the background, and white is used more often in the base color. The extraction of pigment samples also indirectly indicates the location and area of color use. The study of the percentage of elements in the pigments, on the other hand, can be used as a reference for the study pattern of the area of color use, and this part will be explained in Chapter Three.

Similarly, in the article "Research on the pigments of the murals of the Kizil Caves" by Su Bomin et al., published in Dunhuang Research, a similar approach is used to illustrate the location of the use of color in the murals, indirectly interpreting the area and region of the use of color using color sampling. It is indicated in this article:

"A total of 55 pigment samples were analyzed, including 18 red samples, nine blue samples, six green samples, 17 black and brown-black samples, and six white samples."

The samples are broken down into their main components by X-diffraction techniques and tabulated to show, for example:

Table 4 Su, B. M. et al. on the Kizil Cave Pigment Ingredient Analysis

Sample No.	Cave NO.	Sample location	Era	Discoloration	Main Ingredients
KZR-012G	Cave 100	Thousand Buddhas on the left side of the left wall of the front room	Third Phase	Green	Chlorocopper ore, Gypsum, Quartz, Calcite

The table shows the distribution of colors in 10 caves, such as New Cave 1, Cave 38, Cave 77, Cave 100, Cave 114, and Cave 186 of the Kizil Caves. This article also points out the problem of color discoloration, which is also a problem that needs to be paid attention to in the study of the area of color use, for example, as indicated in this article:

"All of the black and brownish-black pigments analyzed in this analysis were, without exception, lead dioxide, the discoloration product of lead dan. The profile analysis results of the discolored pigments show that the thinner pigment layers of lead dan are almost completely changed to black lead dioxide."

This paragraph explains that the black color in the murals of the Kizil Caves is discolored by the red pigment Lead Dan. This kind of color change is often seen in the Mogao Caves, so it is necessary to pay special attention to this kind of color change phenomenon in the analytical study of the color use area.

In summary, the research on mural color areas in the Mogao Caves mural painting research was only mentioned and did not start to explain. The research results of the color of the murals of the Kizil caves indirectly explain the distribution area and area of the color and did not systematically study the area, and proportion of the use of color, but the research results of the color of the murals of the Kizil caves provide ideas and supporting evidence for the study of the area of the use of color of the murals of the Mogao Caves in this dissertation, so in the existing research, too small a proportion of studies of color use areas, and this dissertation will be sample and statistically analyze the color of Mogao Cave mural paintings in terms of their specific use areas and ratios, and the details will be shown in the subsequent chapters.

CHAPTER III

RESEARCH METHODOLOGY

A mixed research method, combining qualitative and quantitative methods, was formulated to study the color system of the Mogao Cave mural paintings. The formulation used documentary method, comparative research, visual methodology, fieldwork, interviews, and inductive methods in the qualitative research method and data statistics in the quantitative research method.

Documentary, statistical, fieldwork and interview methods were used in the research for Objective 1. Documentary , comparative and visual methods were used in the study of Objective 2. Statistical and inductive methods were used in the research for objective 3.

It is important to note that in this study, Objective 2 and Objective 3 need to be combined and studied together, and a part of Objective 2 will be analyzed and presented on the statistical basis of Objective 3.

The above is only a brief description of the content of this section, and the specific details of the analysis will be further explained below.

3.1 Step 1

To collect information on the color used in four Buddhist themes in Mogao Cave mural paintings from the Northern Dynasties and the Tang Dynasty.

3.1.1 Research Design

Using the documentary research method, analyze the period background, coloring techniques, and the intrinsic meaning of color expression in four Buddhist-themed Mogao Cave murals. In the application of the documentary method, the literature will be initially screened using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) process. The literature was analyzed using the CARS model (Create a Research Space), which provides an in-depth analysis of the literature through the three steps of Establishing a Territory, Identifying a Niche, and Occupying

the Niche. The documentary research method is one of the main methods used in this dissertation. In the pre-preparation for the establishment of the color system of Mogao Caves mural paintings, the basic information of Mogao Caves mural paintings needs to be analyzed, so the authoritative Dunhuang scientific information needs to be studied and researched to lay a sound theoretical foundation for the formulate of the color system of Mogao Caves mural paintings.

In the process of studying the color of Mogao Cave murals of four themes, the statistical method will be used. It is necessary to select samples of murals with different themes, analyze the distribution of colors according to the selected samples, and then summarize the existing research on pigments and techniques in Chapter II.

The fieldwork method will analyze the background, content, and color of Mogao Cave mural paintings. In the early stage of the study, the basic information about the color of the Mogao Caves mural paintings will be understood and recorded through fieldwork, and the state of the color on the walls will be observed and recorded in detail.

The interview method is mainly used in the early stage of the study to understand the overall condition of the color of the Mogao Caves mural paintings and the establishment of the color system. In this study, we will also look for authoritative scholars engaged in Dunhuang studies to conduct interviews to understand their views on the color of the Mogao Cave mural paintings and provide more supporting evidence for establishing a new color system.

3.1.2 Population and Sample

Many books, literature, and reports related to the Mogao Cave mural paintings will be collected using the documentary research method, and the overall number is too large. Therefore, when selecting samples, the following qualifying criteria are set:

1. Books published by authoritative publishers and authored by experts in the field of Dunhuang art research are selected

2. Literature related to the color of Mogao Grottoes murals in authoritative journals.

3. Reports and interviews with authoritative art critics on the color of Mogao Cave murals in authoritative newspapers and media.

4. selected content related to the contemporary background, coloring techniques, and the inner meaning of color expression in Mogao Cave mural paintings.

In the use of statistical methods, Mogao Caves in the Northern Dynasties and the Tang Dynasty caves in a total of 330, in selection samples were proposed the Mogao Caves in the Northern Dynasties to the Tang Dynasty each period of representative caves, and the representative caves were selected with a clear color characteristic of the era of the four Buddhist themes mural paintings. Specific samples are listed below:

1. Northern Liang period North wall of Cave 272 Buddha Preaching paintings

2. Early Tang period South wall of Cave 57 Buddha Preaching paintings

3. Northern Zhou period Top of Cave 290 Buddha's life stories paintings

4. Early Tang period South wall of Cave 57 Buddha's life stories paintings

5. Northern Wei period North wall of Cave 254 Jātaka of The King Deer with Nine Colors

6. Northern Zhou period East wall of Cave 428 Jātaka of Prince Sattva Sacrificing Himself to Feed a Tiger

7. Early Tang period North wall of Cave 321 The Sutra painting of Amitabha Buddha

8. Flourishing Tang period South wall of Cave 172 The Sutra painting of Amitayus

In using the fieldwork method, a total of 492 caves in Mogao Caves were painted with mural paintings, which is a huge number, so eight caves were selected for fieldwork according to the following limitations:

1. Caves that are currently open to visitors were selected.

2. Cave selection is limited to the Northern Dynasties and the Tang Dynasty period.

3. Selection of caves with a distinct period as the object of study

The eight caves are:

Cave 275 (Northern Liang period)

Cave 257 (Northern Wei period)

Cave 285 (Western Wei period)

Cave 461 (Northern Zhou period)

Cave 057 (Early Tang period)

Cave 320 (Flourishing Tang period)

Cave 159 (Middle Tang period)

Cave 156 (Late Tang period)

In using the interview method, faced with the fact that there are numerous experts and scholars in the field of Dunhuang science and art research, it would be helpful to limit the candidates to professors or authoritative experts from Chinese universities who have long been engaged in the research of Mogao Cave mural paintings. Designers whose work brings them into contact with the colors of Mogao Cave murals will also be selected for interviews.Six people will eventually be selected (including 2 Chinese experts, 1 international expert; 2 Chinese designers, 1 international designer)

3.1.3 Instruments

In the documentary research method, the tools proposed to be used are:

1. Dunhuang Academy (https://www.dha.ac.cn)

2. The "Digital Dunhuang" Library (https://www.e-dunhuang.com)

The "Digital Dunhuang" website is a virtual project developed by the Dunhuang Research Institute. Its primary role is to utilize computer and digital image technology to permanently preserve and sustainably use Dunhuang Caves' cultural relics. The "Digital Dunhuang" open-source library was officially launched in 2016. In this library, the high-definition mural materials are open source and can be used by researchers. Therefore, all the pictures of Mogao Cave mural paintings in this dissertation are from this library.

3 . CNKI (China National Knowledge Infrastructure) (http://www.cnki.net)

4. Google Scholar (https://scholar.google.com)

5. Library system of Northwest Normal University, China (https://lib.nwnu.edu.cn)

In the use of statistical methods, Excel, Adobe Photoshop, and the "Digital Dunhuang" Library will be used as statistical tools.

In the field method, in-cave recording is proposed, and the recorded data will be summarized and analyzed after the expedition.The tools proposed to be used are Digital note-taking tools.

In the interview method, the proposed use of face-to-face interviews, interview questions will be set from shallow to deep logic, from the history of the development of the color of the Mogao Caves mural paintings to the color development prospects, as a progressive questioning, the current formulation of the question are:

Q1: In developing Mogao Caves mural paintings, what are the characteristics of this stage from the Northern Dynasties to the Tang Dynasty? What is the place of this stage in history?

Q2: Among the mural paintings from the Northern Dynasties to the Tang Dynasty, what mural contents are the most representative?

Q3: In the content of these representative mural paintings, what do you think is the role of color in them? How is the importance of color reflected?

Q4: What do you think about the visual effects of mural painting color?

Q5: Where do you think the uniqueness of the Mogao Caves mural paintings color?

Q6: What are the main aspects of the current research on the color of the Mogao Caves mural paintings?

Q7: Can you give some ideas for adapting the colors used in Mogao Caves mural paintings with current art and design works?

Recording of interviews using mobile phone recording devices.

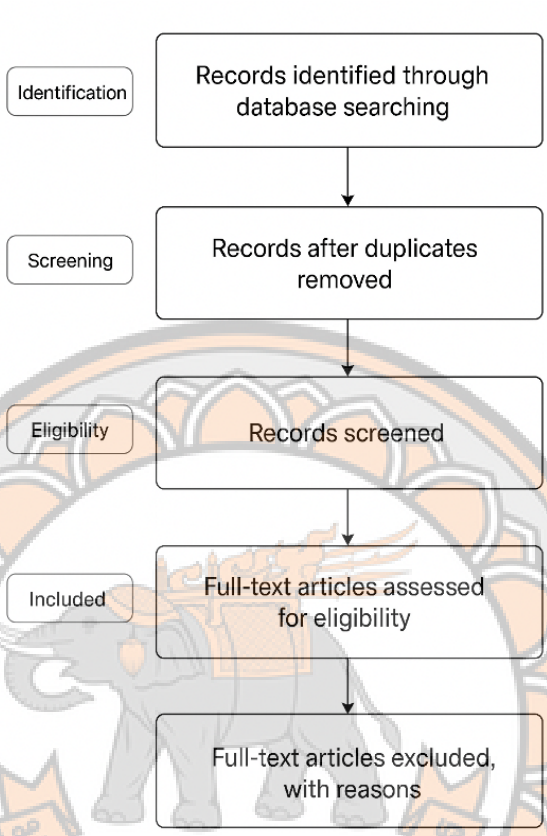
In this study, a total of seven questions were prepared, and three experts and three designers were asked to join the interviews. Among them, there were four Chinese experts and designers and one international expert and designer each.

3.1.4 Data collection

In the documentary research method, data collection primarily involves extracting valid information from existing literature. The sources are primarily published books, searchable journal articles and papers, and news media reports.

And in the process of screening the literature using the PRISMA process, the data collection process will be carried out through the four steps of Identification, Screening, Eligibility, and Included, which are framed in the following table:

Table 5 PRISMA Steps



A total of 84 references related to Dunhuang murals, color theory, and relevant technical methodologies were collected for this study. According to their source platforms and indexing systems, these references can be grouped into three categories. The first category includes international journal articles and conference papers indexed in Web of Science (WoS) and Scopus, such as Heritage Science, Studies in Conservation, Applied Sciences, and Frontiers in Neuroscience, comprising 28 items. The second category consists of Chinese academic papers retrieved from CNKI, Wanfang, and other domestic databases, including journals such as Dunhuang Research, Art Observation, Cultural Relics, Archaeology, and Western Region Studies, totaling 32 items. The third category includes monographs, catalogues, dictionaries, and other published works—for example, The Complete Collection of Dunhuang Murals, Dictionary of Dunhuang Studies, and A General Record of the Contents of the

Mogao Caves—most of which were accessed through Google Scholar, WorldCat, and library catalogues, totaling 24 items.

To further clarify the thematic focus of the literature, the 84 references were categorized according to research content. A total of 35 items relate directly to the historical background of the Mogao Caves, cave typology, conservation history, and archaeological documentation, providing the historical and cultural context for this study. Another 41 items concern mural materials, pigment technology, color theory, and digital color analysis, forming the theoretical and methodological foundation for the study's color analysis framework. In addition, 8 items address Buddhist art history and cross-cultural painting traditions from India and Central Asia, offering supplemental perspectives for understanding color transmission and stylistic origins.

In the statistical method, the data were obtained mainly by collecting, calculating, and counting the available elements in the samples. and presented by way of form.

In the fieldwork method, the primary source of data is observation records.

In the interview method, the source of data is the opinion of the interviewee, and the interviewer will record the relevant data.

3.15 Data analysis

Based on the CARS model, two analysis models were used in the documentary research method: the first one is chronological order, taking the development process of Dunhuang studies as the main line, analyzes the breakthroughs and innovations in the research on the color of four Buddhist-themed Mogao Caves mural paintings in different periods; and the second one is thematic classification, taking the classification of color research as the main line, analyzes the research results of color in various aspects.

In the use of statistical method, the characteristics of the distribution of colors in the mural will be analyzed by counting the distribution of different colors in the mural.

In the fieldwork method, the data collected will be divided into two categories: the shedding, discoloration, and fading of mural colors and the use of different colors in the murals. The causes and current status of each type of problem will be analyzed and organized.

In the interview method, the research significance of the Mogao Cave mural painting color is further deepened by analyzing the viewpoints and conclusions of the

interviewees and enhancing the authority for the formulationt of the Mogao Cave mural painting color system.

3.2 Step 2

To relate the color used in Mogao Cave murals with the visual effects of creating art and design works.

3.2.1 Research Design

In the process of studying the connection between the color and visual effects of the Mogao Cave murals, it is first necessary to examine the relationship between the color of the Mogao Cave murals, the standard color system, and the color of the Eastern Buddhist murals on the Silk Road. The first use of the documentary research method is to better color analysis, and there is a need to define the standard color system, the background, the course of development, and the fundamental theory of the content of the analysis. At the same time, in studying Eastern Buddhist mural paintings on the Silk Road, it is necessary to analyze the location of Buddhist temples and caves along the Silk Road, the number of mural paintings, content, style, technique, and other aspects. Secondly, read Color Image Scale by Shigenobu Kobayashi to understand the research on the formulate of the color scale system in this book and summarize the relationship between the color of the Mogao Cave mural paintings and the visual effects in the works of art and design for the formulate of the color system of the Mogao Cave mural paintings by referring to its research methodology and relating the color to the visual effects. Therefore, when studying this part of the content, it is necessary to read and master many related literature.

The research method used in the color analysis is the comparative method; comparative method is the more critical research method in this dissertation; in the process of formulating the color system of Mogao Caves mural paintings, it is necessary to compare with the other Silk Road on the Eastern Buddhist mural paintings and reference to the standard color system, At the same time for Color Image Scale by Shigenobu Kobayashi as a reference, comparing the process of formulating the color

system in the book, to develop a framework for the color system of the Mogao Cave murals.

At the same time, the comparative method is used to analyze the visual effects of mural colors by borrowing from other color systems, comparing them with the available elements, and combining them with the statistical data of mural colors in the Mogao Caves.

Along with the comparative study method, the visual method will be used to classify the colors of the Mogao Cave murals through different warm and cold, hard and soft colors. The visual analysis method emphasizes the expression of the meaning of visual elements such as color in an image in a cultural context. In this study, the visual analysis focuses on the symbolism and areas of use of colors in the murals.

In this step, statistical methods will also be employed "dual-tool complementary" methodological framework. Two statistical methods will be employed in this study. Tool A identifies color distribution trends based on visual experience, serving as a qualitative exploration; Tool B achieves quantitative color localization through precise CMYK numerical coordinate calculations. Together, they form a complete pathway from trend recognition to numerical validation, ensuring research outcomes possess both visual intuitiveness and data scientific rigor.

The first is colors will be differentiated through the relationship between Cold and Warm, Hard and Soft, To enable a more intuitive understanding of color's properties. The second method involves distributing colors to precise positions based on the distinct CMYK values of each color, thereby presenting color distribution patterns more objectively.

3.2.2 Population and Sample

In using the documentary research method, the number of books, literature, and reports on the standard color system and Eastern Buddhist mural paintings on the Silk Road is large, so the following qualifications are made in selecting the samples:

1. Books published by authoritative publishers and authored by experts and scholars in the field of color studies and Buddhist mural paintings are selected

2. Literature related to the standard color system and Buddhist mural paintings on the Silk Road published in authoritative journals

3. Selected authoritative newspapers, media, authoritative art critics of the standard color system, Silk Road Buddhist mural painting-related reports and interviews

4. Color Image Scale by Shigenobu Kobayashi

In using the comparative method, the scope of the comparison made is limited to the following aspects:

1. Historical context
2. Fundamental principles
3. Structural framework
4. Color techniques
5. Stylistic characteristics
6. Current development
7. Color Statistics and Analysis

Meanwhile, when using the comparative method to analyze visual effects，after the color extraction and statistics are completed, the color of the Mogao Cave murals will be further analyzed. The preliminary plan is to analyze the following aspects:

1. Hue contrast
2. Light and dark contrast
3. Warm and cold contrast
4. Complementary color contrast
5. Chromaticity contrast

In statistical analysis, based on the color collection results, a total of 400 color samples were collected, and their corresponding CMYK values were systematically statistically analyzed. As a subtractive color model composed of four channels—cyan (C), magenta (M), yellow (Y), and black (K)—CMYK's numerical structure fully reflects the hue, saturation, and brightness characteristics of colors in printing and physical media. By statistically analyzing the overall distribution, proportional relationships, and interactive structures across the four channels, this study effectively reveals the general trends, typological structures, and numerical characteristics of the sample colors within the color gamut. This provides foundational data support for subsequent color clustering, distribution model construction, and visual feature analysis.

While all the colors in the Mogao Cave murals will be covered in the visual method, only the collected colors of the Mogao Cave murals that are still circulating and in use in the market are used in this study. The collection will be shown in step 3.

3.2.3 Instruments

In the documentary research method, the tools formulated for use are:

1. CNKI (China National Knowledge Infrastructure) (http://www.cnki.net)
2. The "Digital Dunhuang" Library
3. Google Scholar (https://scholar.google.com)
4. Naresuan University Library System (https://www.lib.nu.ac.th/web/)
5. Xinjiang Digital Library of China (https://www.xjlib.org)

In the comparative method, EndNote will be used. research is formulated using analysis, tabulation, and summarization based on the information obtained from the documentary and color comparison data.

Tools that will be used in the Visual Method:

1. Python
2. Procreate
3. Adobe Photoshop

Tools that will be used in the statistical method:

1. Graphical Tool A:

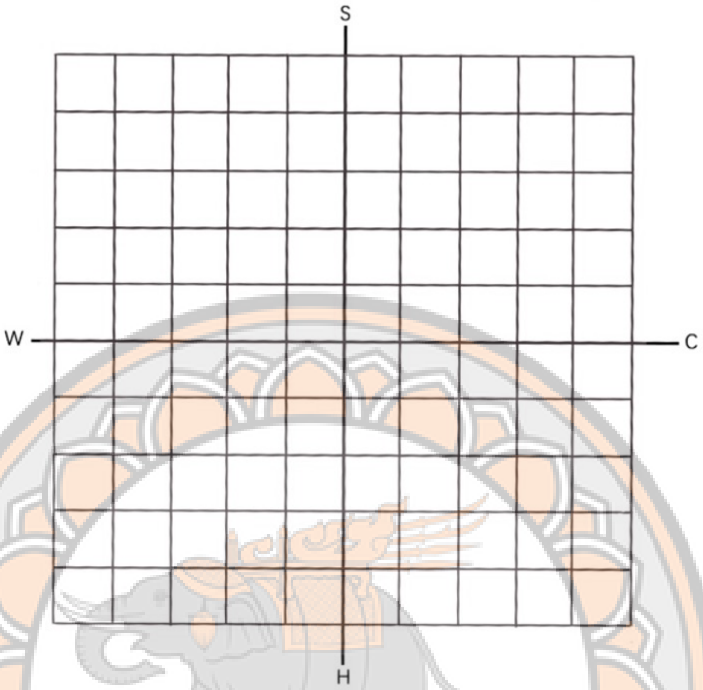


Figure 33 Graphical tool A

From bottom to top, from Hard to Soft, and from left to right, from Warm to Cold, the colors are divided into four zones:

Zone 1: Soft-Warm (SW) zone;

Zone 2: Soft-Cold(SC) zone;

Zone 3: Hard-Warm(HW) zone;

Zone 4: Hard-Cold (HC) zone.

2. Microsoft Excel

3. Graphical Tool B:

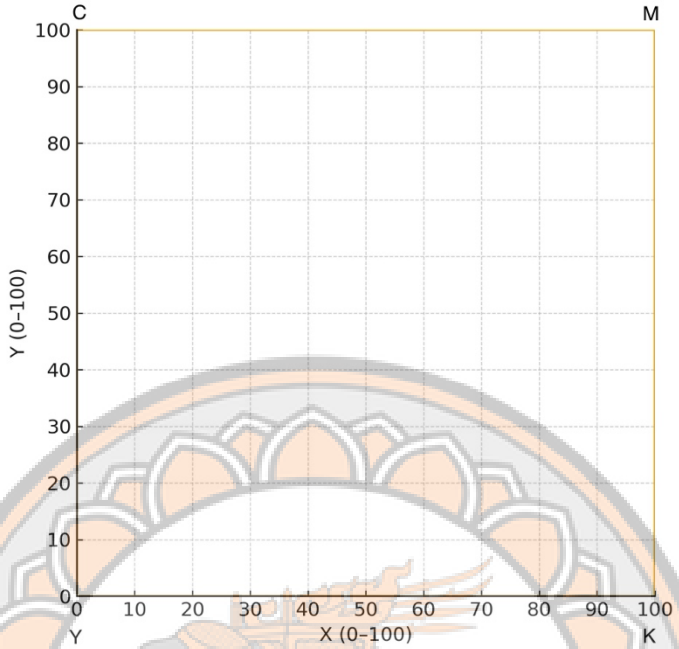


Figure 34 Graphical tool B

3.2.4 Data collection

In the documentary research method, data collection is mainly based on extracting valid information from documentary sources. The sources are primarily published books, searchable journal articles and papers, and news media reports. Refer to Table 5 for detailed steps.

In the comparative method, data is mainly collected by comparing the information obtained in documentary research. The information generated from the comparison is analyzed and organized, and finally, conclusions are drawn.

In this study, the visual method is used to observe and interpret the colors of Mogao Cave murals, so the core of data collection lies in the acquisition of image data and the extraction of color information.

The dataset for statistical method comprises 400 color samples, all extracted from original images according to fixed rules. Each sample underwent repeated sampling and conversion to CMYK mode to ensure numerical stability and comparability. The organized data form the primary analytical sample for this research.

3.2.5 Data analysis

The documentary research method will be based on the CARS model, used theoretical approach carried out from two aspects. First, the standard color system will be taken as the main line, and the causes and current situation of the standard color system will be analyzed. Secondly, taking the Buddhist mural paintings on the Silk Road as the main line, we will examine the historical background, color techniques, stylistic features, and other aspects of these paintings and explore the advantages and shortcomings of the current research situation. On the other hand, the Color Image Scale by Shigenobu Kobayashi was studied, and the method of color analysis was analyzed and summarized.

The comparative research method is to be carried out at two levels. First, the horizontal comparison method compares the color of Mogao Caves mural paintings of the same period with those of other Eastern Buddhist paintings on the Silk Road. Secondly, after finding the commonality of the cave mural paintings, the cross-comparison method is used to compare them with the standard color system to find the commonalities between the two and prove that the color of Mogao Caves mural paintings can become an independent color system. On the other hand, we compare the color scale study in Color Image Scale by Shigenobu Kobayashi with the color of Mogao Cave mural paintings and analyze the research methods in Color Image Scale that can be used to formulate the color system of the Mogao Cave mural paintings.

When using the comparative method to analyze visual effects, the statistical data are compared and analyzed concerning the composition of other color systems, and their feasibility in the color system of Mogao Cave murals is analyzed through the definition and expression of the 5 aspects of the selected samples in other color systems.

This study adopts the visual analysis method to systematically analyze the colors in the murals of Mogao Caves, focusing on the classification of colors, areas of use and religious symbolism. First, in terms of color classification, the colors in the murals are divided into four categories: cold, warm, soft and hard, based on visual parameters such as hue, brightness and saturation. Hue judgment is based on traditional color science standards, such as red, orange, yellow for warm colors, blue, cyan for cold colors; soft and strong based on the saturation and brightness of the color distinction, thereby defining their characteristics.

In the statistical method, the specific calculation formula and process are as follows:

First, express the CMYK values as percentages (0–100 is fine) and compute their total:

$T=C+M+Y+K$

If mixing colors under a "total ink limit of 100%," then theoretically:

$T=100$

But even if it is not exactly 100, that is fine—we can normalize the values:

$c=T/C, m=T/M, y=T/Y, k=T/K$

After normalization,

$c+m+y+k=1$

At this point, we define the coordinate of point P as a weighted average of the four corners of the square.

Corner coordinates:

C corner: (0, 1)

M corner: (1, 1)

Y corner: (1, 0)

K corner: (0, 0)

Point P coordinates:

$x=m\cdot 1+y\cdot 1+c\cdot 0+k\cdot 0=m+y$

$y=c\cdot 1+m\cdot 1+y\cdot 0+k\cdot 0=c+m$

Converted into percentage coordinates (0–100 grid):

$X=100\times(M+Y)/(C+M+Y+K)$

$Y=100\times(C+M)/(C+M+Y+K)$

Based on the above calculation method, the automatic computation of color coordinates was implemented using Excel tools. Furthermore, Tool B was employed to achieve data visualization.

After making the color chart in this way, the symbolism and areas of use of the colors in the color chart will be analyzed for different visual parameters.

3.3 Step 3

To formulate an independent Mogao Cave mural painting color system focusing on the paintings created in the Northern Dynasties and the Tang Dynasty.

3.3.1 Research Design

In formulating the color system of Mogao Caves mural paintings, it is first necessary to use the statistical method. Data statistics methods usually appear in the research on mural painting pigment. This way, through the steps of counting data, organizing data, and presenting the list, it can clearly show the changes in the data.

First of all, we need to count the colors of the Mogao Cave murals that are still being used and circulated in the market, make a color chart based on these colors, then select murals from different periods as samples, make up the colors of the samples, extract the colors in the murals, and make a color chart. The above statistics are used to analyze the basic situation of pigments, the distribution area of colors and techniques.

After the color analysis, the color system of Mogao Caves mural paintings is summarized and analyzed for its ultimate use and benefit. This is the last and most crucial part of studying the color system of Mogao Cave mural paintings.

In this part of the study, inductive methods will be used. When using the inductive method, the results of the color analysis are first observed, then the patterns are identified, and finally, they are summarized into a complete color system.

3.3.2 Population and Sample

When using the statistical method to analyze the pigment information, all the mineral pigments were taken as the overall study, and the mineral pigments still circulating and used in the market and related to the Mogao Cave murals were selected as the samples.

In using statistical methods to analyze the area of color distribution, Mogao Caves in the Northern Dynasties and the Tang Dynasty caves in a total of 330, in selection of samples were proposed the Mogao Caves in the North Dynasties to the Tang Dynasty each period of the representative caves, and in the representative caves were selected with a transparent color characteristic of the era of the mural paintings. The sample selection criteria are the cave mural paintings recognized as the most representative of the period's style in the authoritative literature; see 2.1.1 for details. Respectively:

1. Northern Liang Period: Cave 275 (West Side of North Wall- Jātaka of the King Vilenjeli)

2. Northern Wei Period: Cave 257 (West Wall- Jātaka of The King Deer with Nine Colors (topical)

3. Western Wei period: Cave 285 (Center of the North Wall- Portraits of Providers)

4. Northern Zhou Period: Cave 461 (West Wall- Picture of Disciples)

5. Early Tang Period: Cave 57 (Left Side of the South Wall- Portrait of Avalokiteśvara (Guanyin))

6. Flourishing Tang Period: Cave 320 (Upper Part of the South Wall- Picture of Flying Apsaras)

7. Middle Tang Period: Cave 159 (South Side of the East Wall- Picture of Tubo Zangpo Performing a Buddhist Rite)

8. Late Tang Period: Cave 156 (Lower Part of the South Wall- Picture of Zhang Yichao's Travels)

In using the statistical method to analyze the technique, the 8 color charts used for the visual effects study in Objective 2 were used as the overall population, and 6 groups of colors were randomly selected as samples in the color charts.

In the use of the induction method, the types of generalization are limited to:

1. Inductive generalization
2. Statistical generalization
3. Analogical reasoning

3.3.3 Instruments

The tools used in the statistical method are:

1. The "Digital Dunhuang" (https://www.e-dunhuang.com)
2. Graphical tool
3. Procreate
4. Adobe Photoshop

The tools used in the inductive method are:

1. EndNote
2. Data visualization tool

3.3.4 Data collection

The data were obtained mainly by collecting, calculating, and counting the available sample elements using the statistical method.

In the inductive method, data are derived from the findings of the previous step.

3.3.5 Data analysis

In the study of pigment information using statistical methods, the names, color cards, ores, chemical formulas, stability, and whether or not the pigments were used in the Mogao Cave murals will be counted and analyzed.

When using statistical methods to study the area of color distribution, color restoration of the selected samples is an integral part of establishing the mural paintings' color system because the Mogao Cave mural paintings have different degrees of shedding and discoloration due to various factors such as old age and human damage to more accurately study the distribution of colors, it is necessary to restore the shedding and discoloration of the mural paintings before extracting the colors. The standard of restoration is the research results of Su Bomin et al. on the color discoloration of Mogao Cave mural paintings and the restoration of pigment composition in different areas of the mural paintings. (See 2.1.3, 2.4.2 for details). Restoration of color only, excluding restoration of other elements. (e.g., modeling, outlines, etc.)

After the color restoration of the samples, it is necessary to import the images of the mural paintings into the computer to ensure the comprehensiveness and accuracy of the color of the mural paintings. The software extracts the colors in the CMYK color mode to make a 256-color color chart. Then, each color will be classified and counted to sort out the variation of light, dark, and depth of each color, and then the area of each color used in the mural painting will be calculated.

When using statistical methods to study the technique, six groups of randomly extracted colors will be simulated with different sequences of overdyeing, and the transparency will be changed to observe the effect of different overdyeing.

The inductive method mainly summarizes the results of previous research to explain the rationality and necessity of formulating the color system of Mogao Cave murals.

CHAPTER IV

RESULTS

The purpose of this chapter is to systematically analyze the process of the formation of the color system of the Mogao Caves murals. This study attempts to formulate the color system of Mogao Cave murals through a comprehensive analysis of the literature and statistical data on the color of murals of different periods and themes in the Mogao Caves. The historical background of Mogao Cave murals and the current status of color research have been explored in the previous chapters. In this chapter, the data on murals' colors in terms of pigments, distribution, visual effects, and techniques will be analyzed through the data statistics, comparisons, and other research methods demonstrated in Chapter 3. The research in this chapter reveals the evolution law and systematic framework of Mogao Cave mural painting colors, shows the data analysis process and research results, and provides a reference for the application of Mogao Cave mural painting colors in art and design.

Since in this study Objective 2 and Objective 3 need to be studied at the same time, in Chapter 4 the content will be presented according to the sequential steps of the study.4.1 will correspond to Objective 1, 4.4 will correspond to Objective 2, and 4.2, 4.3, 4.5 and 4.6 will correspond to Objective 3.

Abbreviations :

1. R: Red
2. G: Green
3. B: Blue
4. Y: Yellow
5. P: Purple
6. BL: Black
7. WH: White
8. FB: Face & Body
9. BG: Background
10. CH: Clothing & Headlight
11. AN: Animals
12. LD: Landscape & Decoration
13. OL: Outline
14. S: Soft
15. H: Hard
16. C: Cold
17. W: Warm
18. SW: Soft-Warm
19. SC: Soft-Cold
20. HW: Hard-Warm
21. HC: Hard-Cold

4.1 Color Distribution of the Four Theme Murals

The mural paintings of Mogao Caves are colored differently according to various themes and eras. Therefore, 8 samples of Mogao Cave murals were selected to analyze the changes in color distribution through different themes and eras.

Buddha Preaching paintings, a mural painting, appeared in the Mogao Caves during the Northern Liang period and continued until the Tang Dynasty. Here, we will take two Buddha Preaching paintings from Cave 272 in the Northern Liang period and Cave 57 in the early Tang period as examples and analyze the differences in the distribution of the colors in these paintings.

Figure 35 Cave 272
Buddha Preaching paintings

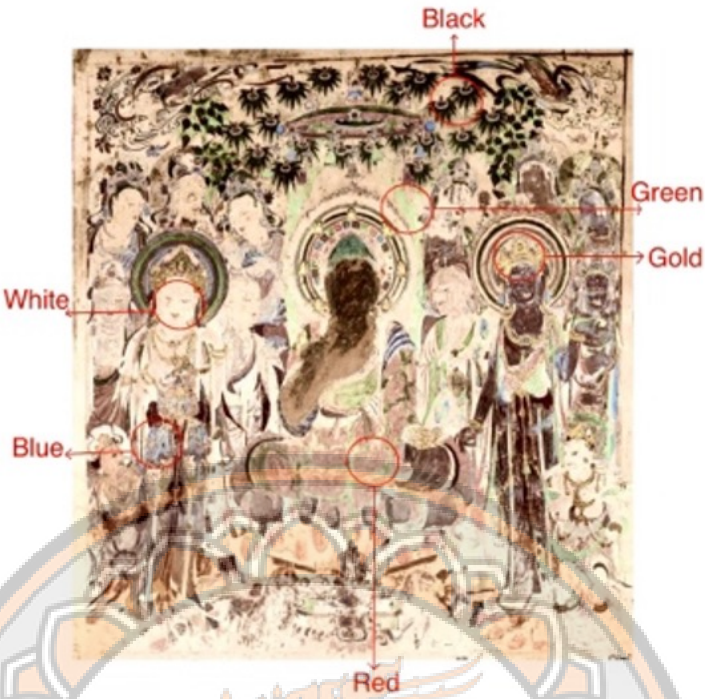


Figure 36 Cave 57 Buddha Preaching paintings

Buddha's life stories paintings were a frequent theme in Mogao Caves during the Northern Dynasties and gradually decreased during the Tang Dynasty. Here, two paintings of Buddha's life stories from Cave 290 of the Northern Zhou period and Cave 57 of the early Tang period are taken as examples to analyze the differences in color distribution.

Figure 37 Cave 290 Buddha's life stories paintings

Figure 38 Cave 57 Buddha's
life stories paintings

Jātaka stories paintings were a recurring theme in the early Mogao Caves, mainly during the Northern Dynasties, with fewer Jātaka stories paintings in the Tang Dynasty. Therefore, we cite Jātaka of The King Deer with Nine Colors from Cave 254 of the Northern Wei Dynasty and Jātaka of Prince Sattva Sacrificing Himself to Feed a Tiger from Cave 428 of the Northern Zhou Dynasty to analyze the changes in the distribution of colors in the Jātaka stories paintings in the early and late periods of the same dynasty.

Figure 39 Cave 254 Jātaka of
The King Deer with Nine Colors

Figure 40 Cave 428 Jātaka of Prince
Sattva Sacrificing Himself to Feed a Tiger

Although The Sutra paintings appeared in the Northern Dynasties period, very few The Sutra paintings of the Northern Dynasties period remain in the existing Mogao Caves murals. At the same time, the Tang Dynasty was the peak period of the development of Sutra paintings. Therefore, we choose The Sutra painting of Amitabha Buddha from Cave 321 in the early Tang period and The Sutra painting of Amitayus from Cave 172 in the Flourishing Tang period as examples to analyze the changes in the color distribution of The Sutra paintings during the initial development and the peak period.

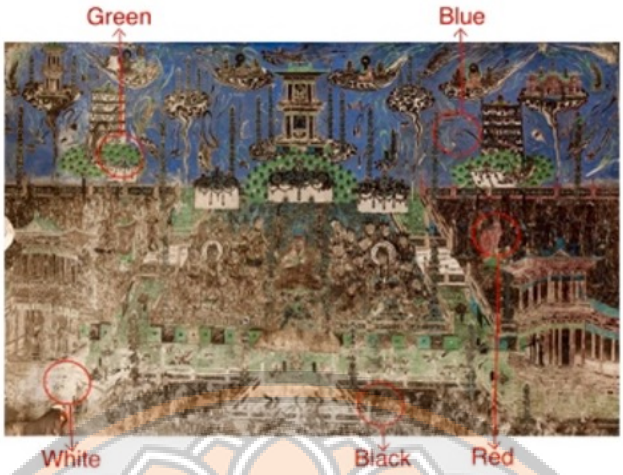


Figure 41 Cave 321 The Sutra painting of Amitabha Buddha

Figure 42 Cave 172 The Sutra painting of Amitayus

The specific color distribution statistics are shown in the following tables:

Table 6 Color Distribution

Theme	Color	Color Distributions											
		FB		BG		CH		AN		LD		OL	
Buddha Preaching Paintings	Red			●		●	√				√		
	Green					●	√			●	√		
	Blue						√				√		
	Black					●	√				√	●	√
	White	●			√	●	√			●	√		
	Yellow												
	Gold						√						
Northern Dynasties（●） Tang Dynasty（√）													
Buddha's Life Stories Paintings	Red				√	●		●					
	Green						√			●	√		
	Blue						√			●	√		
	Black					●	√	●	√	●	√	●	√
	White	●	√	●			√				√		
	Yellow						√				√		
	Gold												
Northern Dynasties（●） Tang Dynasty（√）													
Jātaka Stories Paintings	Red			●			√				√		
	Green					●				●	√		
	Blue										√		
	Black						√	●	√	●	√	●	√
	White	●			√	●		●					
	Yellow												
	Gold												
Northern Wei Period（●） Northern Zhou Period（√）													
The Sutra Paintings	Red					●	√			●	√		
	Green					●	√			●	√		
	Blue			●			√				√		
	Black					●	√			●	√	●	
	White	●	√	●	√	●	√			●	√		
	Yellow						√				√		
	Gold												
Early Tang period（●） Flourishing Tang period（√）													

4.2 Pigment Variations and Statistics

The pigments used in the Mogao Caves murals are mainly pure natural mineral pigments, and due to their age, the types of mineral pigments used in the Mogao Caves are few and highly limited. Therefore, in this chapter, the feasibility of using mineral pigments in the creation of art and design works will be analyzed by combining the mineral pigments used in the Mogao Caves (see 2.1.3 for details) with the mineral pigments that are still widely used in the market for art and design creation. This chapter is limited to the collection and analysis of pigment types and does not involve analyzing the production methods of pigments.

With the development of modern technology, the types of popular mineral pigments on the market are gradually increasing. This section is a compilation of natural mineral pigments, excluding mineral pigments made from synthetic ores. We are analyzed by pigment, color card, stability, etc.

4.2.1 Red (R)

The red natural mineral pigments circulating in the market at present are Cinnabar, Red coral powder, Agate powder, Red pomegranate, Ochre, Xiangfei, Yanji, Chiku Yanji, Tangerine, Cinnabar soil, Soil red, and Chiku ochre, which are altogether 12 kinds of pigments. According to the nature of the analysis, Cinnabar, Ochre (Iron red), Cinnabar soil, and Soil red four pigments are the Northern Dynasties and Tang Dynasty Mogao Caves mural paintings used the color. The difference is that Mogao Caves mural paintings in iron red in the addition of quartz and clay, resulting in a decline in the stability of the color, are prone to discoloration.

Other pigments are natural mineral colors currently circulating in the market, and the specific analysis of their composition is as follows:

(1) Cinnabar (HgS) is highly stable and has high light resistance but is sensitive to acidic environments and is not resistant to high temperatures.

(2) Red coral powder ($CaCO_3$) is relatively stable but sensitive to acidic environments, and prolonged exposure to bright light may lead to color fading or deterioration.

(3) Agate powder (SiO_2) is highly stable. It is not sensitive to environmental changes such as acid and alkali, light, humidity, etc. It is heat-resistant and complex and is not easily scratched or corroded.

(4) Red pomegranate ($(Mg, Fe, Al)_3(SiO_4)_3$) is chemically stable, high hardness, corrosion resistant, acid and alkali resistant, high temperature resistant, and light does not affect its stability.

(5) Ochre (Fe_2O_3) is highly stable. Iron oxide is chemically more inert, resistant to corrosion, acids, and alkalis, and insensitive to light, heat, and humidity changes.

(6) Xiangfei ($Ca_2(Al, Fe)_3(SiO_4)_3(OH)$) is relatively stable chemically and insensitive to acids and bases.

(7) Yanji ($(Ca, Na)(Al, Si)_4O_8$) is chemically stable and resistant to acids and alkalis. Its heat resistance is also good, but its hardness is medium.

(8) Chiku Yanji ($(Ca, Na)_{2\text{-}3}Al_3(Al, Si)_2Si_{13}O_{36}\text{-}12H_2O$) is highly stable but does not resist heat.

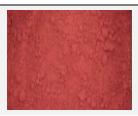
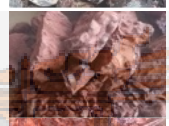
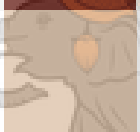
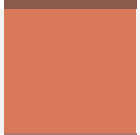
(9) Tangerine ($PbCrO_4$) is stable at normal temperatures and somewhat light-sensitive.

(10) Cinnabar soil ($CaCO_3$) is relatively stable but sensitive to acidic environments.

(11) Soil red ($CaCO_3$+ Fe_2O_3) is relatively stable, and calcium carbonate in marl is sensitive to acid and easily eroded by acid. Iron oxides are more stable, but the clay content may be affected by humidity.

(12) Chiku ochre ($(Na,K)Al_4Si_4O_{12}$) is stable and insensitive to acids and bases. It has good heat resistance, high hardness, and the ability to adapt to environmental changes.

Table 7 Pigment Analysis: Red

Name	Pigments	Color Card	Ores	Ore name (chemical formula)	Stability	Used in existing murals
Cinnabar（R1）				Limestone HgS	Stable	Yes
Red coral powder（R2）				Red Coral $CaCO_3$	Relative stable	No
Agate powder（R3）				Agate SiO_2	Stable	No
Red pomegranate（R4）				Garnet $Fe_3Al_2(SiO_4)_3$/ $Mg_3Al_2(SiO_4)_3$	Stable	No
Ochre（R5）				Iron Ore Fe2O3	Stable	Yes
Xiangfei（R6）				Epidote $Ca_2(Al,Fe)_3(SiO_4)_3(OH)$	Stable	No
Yanji（R7）				Bytownite $(Ca,Na)(Al,Si)_4O_8$	Stable	No
Chiku Yanji（R8）				Heulandite $(Ca,Na)_{23}Al_3(Al,Si)_2Si_{13}O_{36}\cdot 12H_2O$	Stable	No
Tangerine（R9）				Crocoite $PbCrO_4$	Stable	No
Cinnabar soil（R10）				Red Marl $CaCO_3$	Relative stable	Yes
Soil red（R11）				Chalk $CaCO_3$+ Fe_2O_3	Relative stable	Yes
Chiku ochre（R12）				Nepheline $(Na,K)Al_4Si_4O_{12}$	Stable	No

4.2.2 Green (G)

Today, the market has nine green pigments: Stone green, Grass green, Olive green, Chun, Jasper stone powder, Lijiu, Bai Cui powder, Yellow-green, and Light green. Stone green was used in the surviving mural paintings of the Mogao Caves of the Northern Dynasties and the Tang Dynasty and is made from malachite. Other pigments were made from different ores. It is worth mentioning that in the Mogao Cave murals, stone green made from color copper ore was also used, which was caused by the lack of pigment resources in ancient times, while modern pigment resources and transportation efficiency have greatly improved, so stone green is usually made from malachite, which is of higher purity and better color rendering.

Their specific composition is analyzed as follows:

(1) Stone green ($Cu_2CO_3(OH)_2$) is highly stabilized in the natural environment but easily dissolves in an acidic environment.

(2) Grass green($(Cu, Al)_2H_2Si_2O_5(OH)_4$-$nH_2O$ is less stable, easy to decompose, and especially unstable in wet or acidic environments.

(3) Olive green ($Cu_2Cl(OH)_3$) is highly stable but decomposes quickly in strongly acidic environments.

(4) Chun ($Ca_2(Al, Fe)_3(SiO_4)_3(OH)$) is highly stable and durable in most geological environments.

(5) Jasper stone powder (SiO_2) is highly stable and is not easily weathered or dissolved.

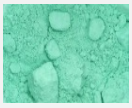
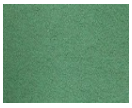
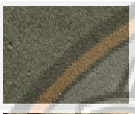
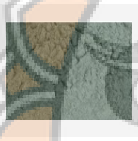
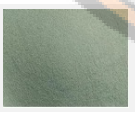
(6) Lijiu (MnS_2) is less stable and easily oxidized in oxidizing environments.

(7) Bai Cui powder ($KAlSi_3O_8$) is highly stable and not easily decomposed in acid and alkali environments.

(8) Yellow-green ($Ni_3(AsO_4)_2$-$8H_2O$) is quickly dissolved under wet conditions and is unstable.

(9) Light green ($CuSO_4$-$5H_2O$) is highly unstable, easily dissolved in water, and dehydrated under dry conditions.

Table 8 Pigment Analysis: Green

Name	Pigments	Color Card	Ores	Ore name (chemical formula)	Stability	Used in existing murals
Stone green（G1）				Malachite $Cu_3(CO_3)_2(OH)_2$	Stable	Yes
Grass green（G2）				Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$	Less stable	No
Olive green（G3）				Chlorocopper $Cu_2Cl(OH)_3$	Stable	Yes
Chun（G4）				Epidote $Ca_2(Al,Fe)_3(SiO_4)_3(OH)$	Stable	No
Jasper stone powder（G5）				Jasper SiO_2	Stable	No
Lijiu（G6）				Hauerite MnS_2	Less stable	No
Bai Cui powder（G7）				Amazonite $KAlSi_3O_8$	Stable	No
Yellow green（G8）				Annabergite $Ni_3(AsO_4)_2 \cdot 8H_2O$	Less stable	No
Light green（G9）				Chalcanthite $CuSO_4 \cdot 5H_2O$	Unstable	No

4.2.3 Blue (B)

The five blue pigments on the market today are mainly Stone blue, Lapis lazuli powder, Turquoise powder, Ziyun powder, and Blue-gray. Stone blue and lapis lazuli were used in the surviving mural paintings of the Mogao Caves of the Northern Dynasties and the Tang Dynasty. Stone blue is made of blue copper ore, and lapis lazuli is an ancient type of pigment. Other pigments are made from different ores.

Their specific compositions are analyzed as follows:

(1) Stone blue ($Cu_3(CO_3)_2(OH)_2$) is stabilized in the natural environment and dissolves in acid.

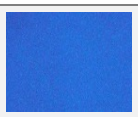
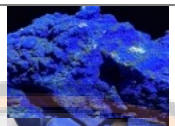
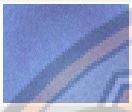
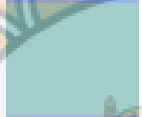
(2) Lapis lazuli powder ($(Na, Ca)_8(AlSiO_4)_6(SO_4, S, Cl)_2$) is stable in natural environments but is sensitive to acids and intense heat and corrodes when exposed to acidic conditions, affecting the color.

(3) Turquoise powder ($CuAl_6(PO_4)_4(OH)_8\text{-}4H_2O$) is highly stable but sensitive to acids and heat and is susceptible to discoloration due to exposure to acids or high temperatures.

(4) Ziyun powder ($Na_8(AlSiO_4)_6Cl_2$) is relatively stable but sensitive to acidic environments.

(5) Blue gray ($Fe_3(PO_4)_2\text{-}8H_2O$) will oxidize and change to dark blue or black in an environment with sufficient oxygen. It is chemically less stable when exposed to air for long periods.

Table 9 Pigment Analysis: Blue

Name	Pigments	Color Card	Ores	Ore name (chemical formula)	Stability	Used in existing murals
Stone blue（B1）				Azurite $Cu_3(CO_3)_2(OH)_2$	Stable	Yes
Lapis lazuli powder（B2）				Lapis Lazuli $(Na,Ca)_8(AlSiO_4)_6(SO_4,S,Cl)_2$	Stable	Yes
Turquoise powder（B3）				Turquoise $CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$	Stable	No
Ziyun powder（B4）				Sodalite $Na_8(AlSiO_4)_6Cl_2$	Relative stable	No
Blue gray（B5）				Vivianite $Fe_3(PO_4)_2 \cdot 8H_2O$	Unstable	No

4.2.4 Yellow (Y)

The yellow mineral pigments on the market are mainly Androgynous, Orpiment, Tea color, Qiang cha, Brown, Rock Jiaocha, Gold yellow, Gold tea powder, Rock gold tea, Rock yellow soil, and 10 pigments. Androgynous and Orpiment are in the existing Northern Dynasties, and the Tang Dynasty Mogao Caves murals have been used many times in the color. Both pigments are made from goldstone. All other pigments are made from minerals discovered over time and can be used as pigments.

Their specific composition is analyzed as follows:

(1) Andrographis (As_4S_4) is unstable in light and air and gradually transforms into estrus (As_2S_3).

(2) Orpiment (As_2S_3) is unstable in light and air and is transformed from androgynous.

(3) Tea color ($Pb_2Sb_2O_7$) is relatively stable but is easily decomposed under acidic conditions.

(4) Qiang cha ($FeO(OH)$) is a highly stable common iron oxide that does not usually decompose rapidly in the natural environment.

(5) Brown ($(Ce, La, Th)PO_4$) is highly stable. Still, due to the presence of radioactive elements such as thorium, it will release trace amounts of radioactivity when exposed to natural environments for long periods.

(6) Rock Jiaocha (MnO_2) is highly stable and dissolves under acid.

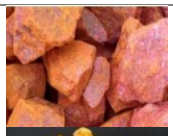
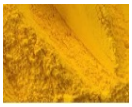
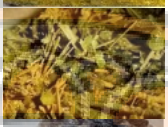
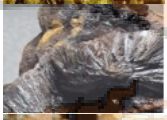
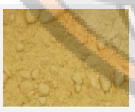
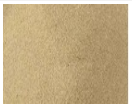
(7) Gold yellow (Hg_2Cl_2) is relatively stable in dry environments, but it is easy to decompose in humid or acidic environments, releasing toxic mercury vapor.

(8) Gold tea powder ($FeO(OH)\text{-}nH_2O$) limonite is highly stable in humid environments, is a product of many weathered iron ores, and dissolves readily under acidic conditions.

(9) Rock gold tea ($(Ca_2)(Mg, Fe)_5Si_8O_{22}(OH)_2$) is highly stable under most geologic conditions, is resistant to weathering and erosion but may be transformed into other minerals under conditions of high temperature and pressure.

(10) Rock yellow soil (SiO_2+CaCO_3) is physically and chemically stable, but its constituents tend to dissolve in acidic environments.

Table 10 Pigment Analysis: Yellow

Name	Pigments	Color Card	Ores	Ore name (chemical formula)	Stability	Used in existing murals
Andrographis（Y1）				Realgar As_4S_4	Less stable	Yes
Orpiment（Y2）				Orpiment As_2S_3	Less stable	Yes
Tea color（Y3）				Bindheimite $Pb_2Sb_2O_7$	Stable	No
Qiang cha（Y4）				Goethite FeO(OH)	Stable	Yes
Brown（Y5）				Monazite $(Ce,La,Th)PO_4$	Stable	No
Rock Jiaocha（Y6）				Pyrolusite MnO_2	Unstable	No
Gold yellow（Y7）				Calomel Hg_2Cl_2	Unstable	No
Gold tea powder（Y8）				Limonite $FeO(OH)\cdot nH_2O$	Stable	No
Rock gold tea（Y9）				Amphibole $(Ca_2)(Mg,Fe)_5Si_8O_{22}(OH)_2$	Less stable	No
Rock yellow soil（Y10）				Loess SiO_2+ $CaCO_3$	Less stable	Yes

4.2.5 Purple (P)

Currently, the market has four main kinds of popular purple pigments: rock ancient purple, bean color, aubergine purple, and camel red. These four pigments in the existing Mogao Caves mural paintings have not appeared, but they were made by the development of the times and the discovery of pigments made since ore.

Their specific compositions are analyzed as follows:

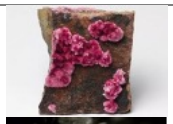
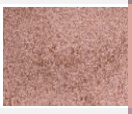
(1) Rock ancient purple ($Co_3(AsO_4)_2$-$8H_2O$) is relatively stable in dry environments but tends to dehydrate and deteriorate in moist environments. It is also readily dissolved under acidic conditions.

(2) Bean color (YPO_4) is highly stable in natural environments and is resistant to weathering and erosion.

(3) aubergine purple ($KAlSi_2O_6$) is relatively stable at room temperature and pressure but may undergo structural changes under high-temperature conditions.

(4) Camel red ($CaFeSi_2O_6$) is more stable in most geologic environments and has better weathering resistance.

Table 11 Pigment Analysis: Purple

Name	Pigments	Color Card	Ores	Ore name (chemical formula)	Stability	Used in existing murals
Rock ancient purple（P1）				Erythrite $Co_3(AsO_4)_2 \cdot 8H_2O$	Relative stable	Yes
Bean color（P2）				Xenotime YPO_4	Stable	Yes
aubergine purple（P3）				Leucite $KAlSi_2O_6$	Stable	No
Camel red（P4）				Hedenbergite $CaFeSi_2O_6$	Stable	No

4.2.6 Black (BL)

Black pigment includes Tourmaline powder, Obsidian powder, Purple black, Brown Black, Rock black, Graphite, and Pyrolite black. Seven kinds of pigment are used, but only Graphite appeared in Mogao Cave mural paintings; the other was a new mineral pigment discovered later.

Their specific compositions are analyzed as follows:

(1) Tourmaline powder ($NaFe_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$) is highly stable under natural conditions, with good resistance to weathering and corrosion and adapted to a wide range of geological environments.

(2) Obsidian powder (SiO_2) is a chemically stable volcanic glass. However, its amorphous structure makes it physically unstable and fragile, and it does not resist long-term weathering.

(3) Purple black (Cu_5FeS_4) is unstable and easily oxidized, especially in humid environments.

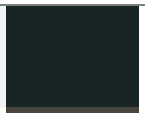
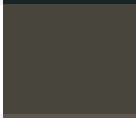
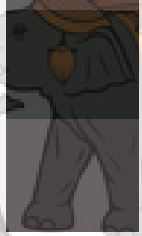
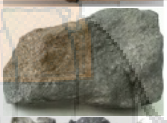
(4) Brown black ($FeWO_4$) is relatively stable in the natural environment but will dissolve in an acidic environment. It is especially easy to react with concentrated acid.

(5) Rock black ($FeTiO_3$) is stable in most natural conditions and resistant to weathering.

(6) Graphite (C) is highly stable at room temperature, has high heat and corrosion resistance, and is oxidized to carbon dioxide or carbon monoxide only at very high temperatures or in strongly oxidizing environments.

(7) Pyrolusite black(MnO_2) is relatively stable but may be reduced in reducing environments and dissolves readily in acidic conditions.

Table 12 Pigment Analysis: Black

Name	Pigments	Color Card	Ores	Ore name (chemical formula)	Stability	Used in existing murals
Tourmaline powder（BL1）				Tourmaline $NaFe_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$	Stable	No
Obsidian powder（BL2）				Obsidian SiO_2	Stable	No
Purple black（BL3）				Bornite Cu_5FeS_4	Less stable	No
Brown black（BL4）				Ferberite $FeWO_4$	Relative stable	No
Rock black（BL5）				Ilmenite $FeTiO_3$	Stable	No
Graphite（BL6）				Graphite C	Stable	Yes
Pyrolusite black（BL7）				Pyrolusite MnO_2	Relative stable	No

4.2.7 White (WH)

Three primary pigments are circulating: Shengshang, Crystal powder, and Calcite powder. Calcite was used in the mural paintings of the Mogao Caves during the Northern Dynasties and the Tang Dynasty. Once used frequently in murals, chalk is no longer a pigment because of its low quality.

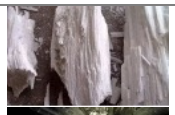
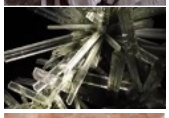
The specific composition of the above pigments is analyzed as follows:

(1) Shengshang ($CaSiO_3$) is highly stable at standard temperature and pressure and has good thermal and chemical stability. Its decomposition temperature exceeds 1540°C and can withstand high temperatures and acidic environments.

(2) Crystal powder (SiO_2) is highly stable at room temperature and pressure and is resistant to acid and alkali corrosion.

(3) Calcite powder ($CaCO_3$) is stable at standard temperature and pressure but easily eroded by acid.

Table 13 Pigment Analysis: White

Name	Pigments	Color Card	Ores	Ore name (chemical formula)	Stability	Used in existing murals
Sheng shang（WH1）				Wollastonite $CaSiO_3$	Stable	Yes
Crystal powder（WH2）				Quartz SiO_2	Stable	Yes
Calcite powder（WH3）				Calcite $CaCO_3$	Stable	No

4.3 Analysis of Visual Effects

This chapter makes a color chart for the pigments collected in 4.1, studies the changes of colors in the same color spectrum with different brightness, contrast, and hue, and further analyzes the visual effects of Mogao Cave mural colors in other situations to make them applicable to the creation of different kinds of art and design works with various contents, and explores more possibilities of Mogao Cave mural colors in modern art. Each color in the color chart will be clearly labeled with its CMYK values and numbers to facilitate more accurate color extraction.

4.3.1 Original Color Chart Analysis

By summarizing the color cards in 4.1, create color table C1 as follows:

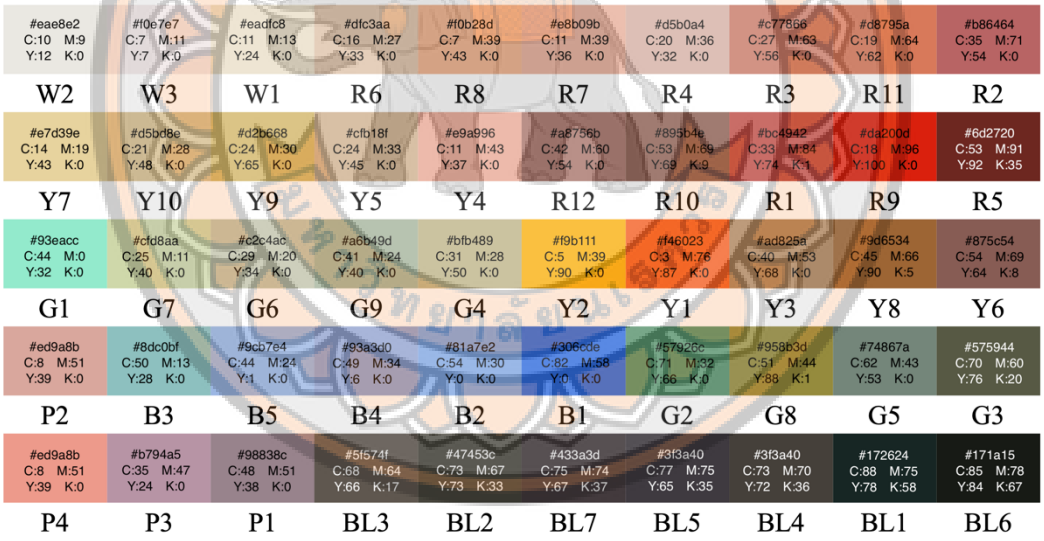


Figure 43 C1

Use the tool A, analysis of the colors in the color chart is shown in CA-1(A):

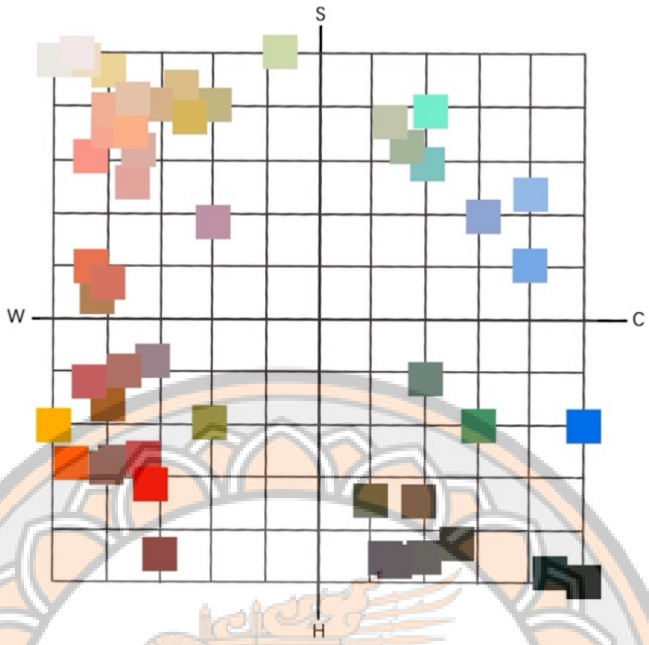


Figure 44 CA-1(A)

Through the color chart, it can be seen that the current market circulation is in line with the Mogao Cave mural color material qualities of the color in the color tendency of the distribution of a relatively uniform, the four zones have a considerable number of colors, the SW zone color distribution is the most, the SC zone color distribution is less. The colors are distributed around the axes, and there is almost no color distribution in the middle, indicating that the colors are mainly complementary, with strong contrasts and no intermediate colors.

Use the tool B, The calculation and statistics of color coordinates are as follows:

Table 14 C1 Coordinate Calculation Table

Color NO.	C	M	Y	K	X coord	Y coord
W2	10	9	12	0	68	61
W3	7	11	7	0	72	72
W1	11	13	24	0	77	50
R6	16	27	33	0	79	57
R8	7	39	43	0	92	52
R7	11	39	36	0	87	58
R4	20	36	32	0	77	64
R3	27	63	56	0	82	62
R11	19	64	62	0	87	57
R2	35	71	54	0	78	66

Y7	14	19	43	0	82	43
Y10	21	28	48	0	78	51
Y9	24	30	65	0	80	45
Y5	24	33	45	0	76	56
Y4	11	43	37	0	88	59
R12	42	60	54	0	73	65
R10	53	69	69	9	69	61
R1	33	84	74	1	82	61
R9	18	96	100	0	92	53
R5	53	91	92	35	68	53
G1	44	0	32	0	42	58
G7	25	11	40	0	67	47
G6	29	20	34	0	65	59
G9	41	24	40	0	61	62
G4	31	28	50	0	72	54
Y2	5	39	90	0	96	33
Y1	3	76	87	0	98	48
Y3	40	53	68	0	75	58
Y8	45	66	90	5	76	54
Y6	54	69	64	8	68	63
P2	8	51	39	0	92	60
B3	50	13	28	0	45	69
B5	44	24	1	0	36	99
B4	49	34	6	0	45	93
B2	54	30	0	0	36	100
B1	82	58	0	0	41	100
G2	71	32	66	0	58	61
G8	51	44	88	1	72	52
G5	62	43	53	0	61	66
G3	70	60	76	20	60	58
P4	8	51	39	0	92	60
P3	35	47	24	0	67	77
P1	48	51	38	0	65	72
BL3	68	64	66	17	60	61
BL2	73	67	73	33	57	57
BL7	75	74	67	37	56	59
BL5	77	75	65	35	56	60
BL4	73	70	72	36	57	57
BL1	88	75	78	58	51	55
BL6	85	78	84	67	52	52

Tool B analysis of the colors in the color chart is shown in CA-1(B):

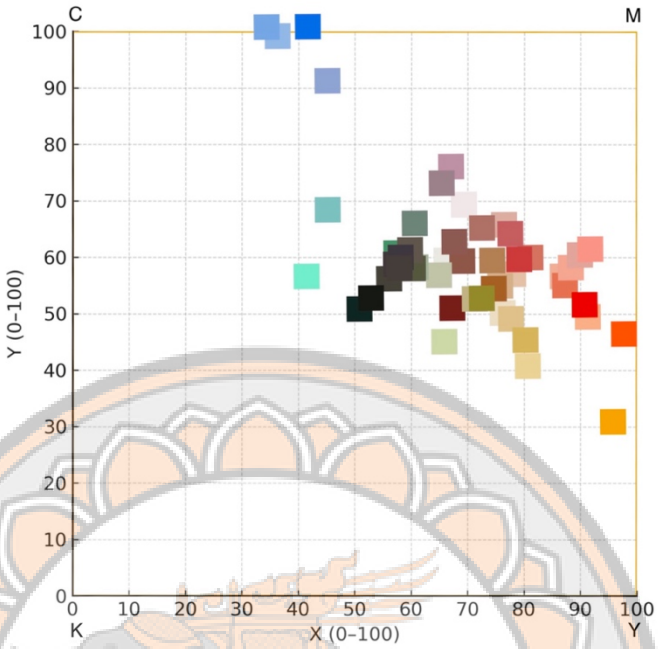


Figure 45 CA-1(B)

The spatial distribution of colors in the diagram reveals a structural pattern progressing from high C to high M and Y: colors with higher C values concentrate in the upper and left regions, forming a cool color zone. As C, M, and Y values converge while K increases, colors cluster toward the center, appearing as neutral tones. With rising M and Y values, colors gradually spread toward the right and lower-right, creating a warm color zone. Combinations of high K with low CMY values are rare, leaving the lower-left region largely vacant. The overall pattern exhibits a gradient transition from cool to warm and from light to dark.

4.3.2 Analysis of Brightness Changes

1) Brightness +100

Adjusting the brightness of the original color table to +100 gives the following color chart C2:

#fdfdfd C:1 M:1 Y:1 K:0	#fdfbfc C:1 M:2 Y:1 K:0	#fcfbf7 C:1 M:2 Y:4 K:0	#fbf7ee C:2 M:4 Y:9 K:0	#fcf0e0 C:0 M:9 Y:14 K:0	#faf0e7 C:1 M:9 Y:10 K:0	#f9f0eb C:2 M:9 Y:8 K:0	#f4cebb C:1 M:28 Y:26 K:0	#f8cfaf C:0 M:28 Y:33 K:0	#eeb9b5 C:2 M:39 Y:22 K:0
W2	W3	W1	R6	R8	R7	R4	R3	R11	R2
#fcfaeb C:2 M:2 Y:11 K:0	#f9f4e1 C:4 M:5 Y:16 K:0	#f9f2c4 C:5 M:6 Y:33 K:0	#f8f1e1 C:3 M:7 Y:15 K:0	#fbeee5 C:1 M:10 Y:11 K:0	#e7c9be C:9 M:27 Y:23 K:0	#d3a895 C:17 M:42 Y:39 K:0	#ee9585 C:0 M:57 Y:42 K:0	#f86543 C:0 M:78 Y:74 K:0	#b45343 C:30 M:84 Y:78 K:0
Y7	Y10	Y9	Y5	Y4	R12	R10	R1	R9	R5
#ecfdf7 C:12 M:0 Y:8 K:0	#f8faef C:5 M:1 Y:10 K:0	#f6f5f0 C:5 M:4 Y:7 K:0	#eef1e8 C:9 M:4 Y:12 K:0	#f4f2dd C:7 M:5 Y:18 K:0	#fdf179 C:6 M:5 Y:68 K:0	#fdba6b C:0 M:39 Y:65 K:0	#ebd5ac C:9 M:20 Y:38 K:0	#e1b672 C:12 M:36 Y:64 K:0	#d2aa9e C:18 M:41 Y:34 K:0
G1	G7	G6	G9	G4	Y2	Y1	Y3	Y8	Y6
#f8ede7 C:2 M:10 Y:9 K:0	#e3f5f5 C:16 M:0 Y:7 K:0	#e9f1fc C:12 M:4 Y:0 K:0	#e2eaf7 C:15 M:6 Y:0 K:0	#d9eafa C:20 M:4 Y:0 K:0	#77bbfa C:58 M:14 Y:0 K:0	#b4dfc1 C:40 M:0 Y:35 K:0	#e1da89 C:40 M:0 Y:35 K:0	#e1da89 C:27 M:11 Y:22 K:0	#9fa283 C:45 M:33 Y:54 K:0
P2	B3	B5	B4	B2	B1	G2	G8	G5	G3
#fbe7dc C:0 M:15 Y:13 K:0	#f1e1eb C:5 M:17 Y:2 K:0	#e1d4db C:13 M:20 Y:9 K:0	#aaa096 C:38 M:37 Y:39 K:0	#858273 C:56 M:48 Y:56 K:1	#7a6d74 C:60 M:60 Y:48 K:1	#746c77 C:63 M:60 Y:46 K:1	#6077 6e C:57 M:54 Y:56 K:1	#314744 C:85 M:64 Y:70 K:31	#2e3128 C:79 M:71 Y:82 K:51
P4	P3	P1	BL3	BL2	BL7	BL5	BL4	BL1	BL6

Figure 46 C2

Use the tool A, analysis of the colors in the color chart is shown in CA-2(A):

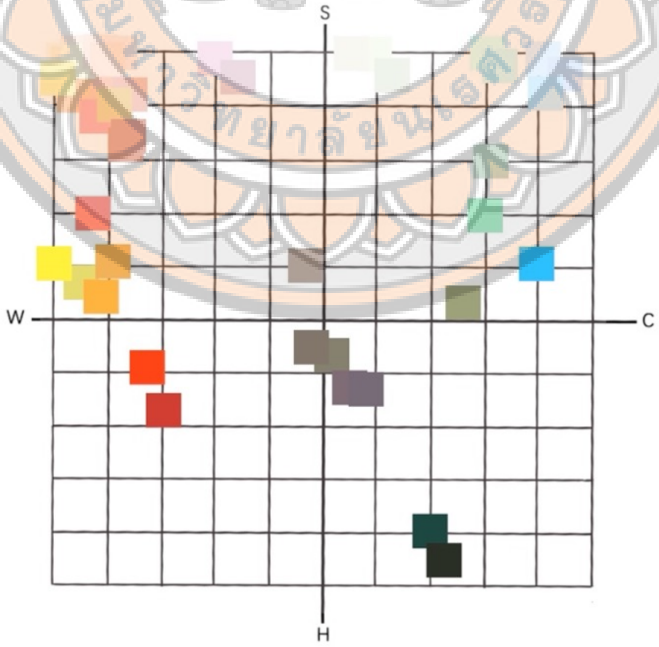


Figure 47 CA-2(A)

The color chart shows that after enhancing the brightness of the original color chart, more than 80% of the colors are distributed in the SW and SC zones, with more than half of the colors distributed around the upper part of the number axis. The original colors in the original HW and HC zones move upward in the upper zones, producing some of the intermediate colors. As the brightness increases, the color contrast decreases, and the initially sharp complementary colors become less intense. The color impact of the complementary color contrast is weakened, and the overall visual effect becomes more harmonious and calm. At the same time, due to the foundation of the complementary color relationship, the sharpness of the color is still retained. Therefore, in this color chart, the conflict of colors is reduced, but the sharpness is not low, showing a soft and bright visual effect.

Use the tool B, The calculation and statistics of color coordinates are as follows:

Table 15 C2 Coordinate Calculation Table

Color NO.	C	M	Y	K	X coord	Y coord
W2	1	1	1	0	67	67
W3	1	2	1	0	75	75
W1	1	2	4	0	86	43
R6	2	4	9	0	87	40
R8	0	9	14	0	100	39
R7	1	9	10	0	95	50
R4	2	9	8	0	89	58
R3	1	28	26	0	98	53
R11	0	28	33	0	100	46
R2	2	39	22	0	97	65
Y7	2	2	11	0	87	27
Y10	4	5	16	0	84	36
Y9	5	6	33	0	89	25
Y5	3	7	15	0	88	40
Y4	1	10	11	0	95	50
R12	9	27	23	0	85	61
R10	17	42	39	0	83	60
R1	0	57	42	0	100	58
R9	0	78	74	0	100	51
R5	30	84	78	0	84	59
G1	12	0	8	0	40	60
G7	5	1	10	0	69	38
G6	5	4	7	0	69	56
G9	9	4	12	0	64	52
G4	7	5	18	0	77	40
Y2	6	5	68	0	92	14

Y1	0	39	65	0	100	38
Y3	9	20	38	0	87	43
Y8	12	36	64	0	89	43
Y6	18	41	34	0	81	63
P2	2	10	9	0	90	57
B3	16	0	7	0	30	70
B5	12	4	0	0	25	100
B4	15	6	0	0	29	100
B2	20	4	0	0	17	100
B1	58	14	0	0	19	100
G2	40	0	35	0	47	53
G8	40	0	35	0	47	53
G5	27	11	22	0	55	63
G3	45	33	54	0	66	59
P4	0	15	13	0	100	54
P3	5	17	2	0	79	92
P1	13	20	9	0	69	79
BL3	38	37	39	0	67	66
BL2	56	48	56	1	65	65
BL7	60	60	48	1	64	71
BL5	63	60	46	1	62	72
BL4	57	54	56	1	65	66
BL1	85	64	70	31	54	60
BL6	79	71	82	51	54	53

Tool B analysis of the colors in the color chart is shown in CA-2(B):

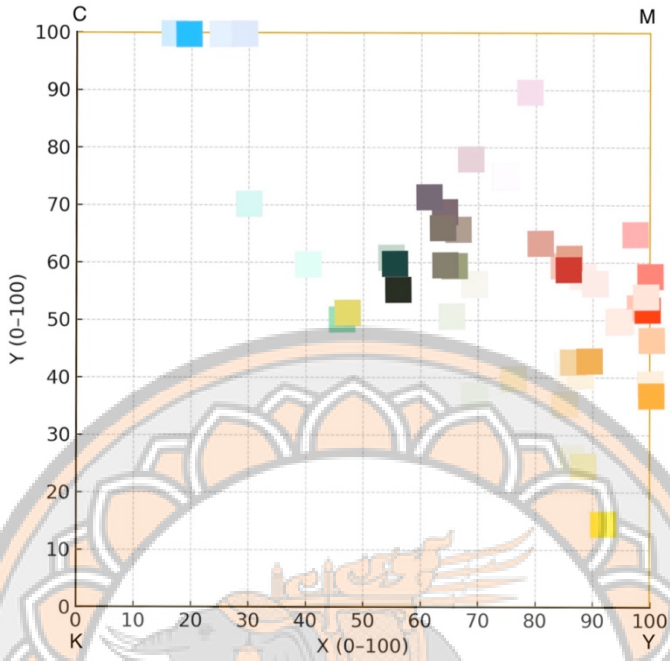


Figure 48 CA-2(B)

The color distribution in the diagram progresses from high Cyan (C) toward higher Magenta (M) and Yellow (Y): the top and left areas predominantly feature cool colors with high Cyan values. When Cyan, Magenta, and Yellow values are close while Black (K) increases, color blocks concentrate in the center, forming low-saturation neutral tones. As Magenta and Yellow increase and Cyan decreases, colors shift noticeably toward the right and lower-right, forming a warm color zone. This overall pattern reflects the CMYK gradient principle of transitioning from cool to warm and from light to dark.

2) Brightness -100

Adjust the brightness of the original color table to -100 to obtain the following color table C3:

Figure 49 C3

Use the tool A, analysis of the colors in the color chart is shown in CA-3(A):

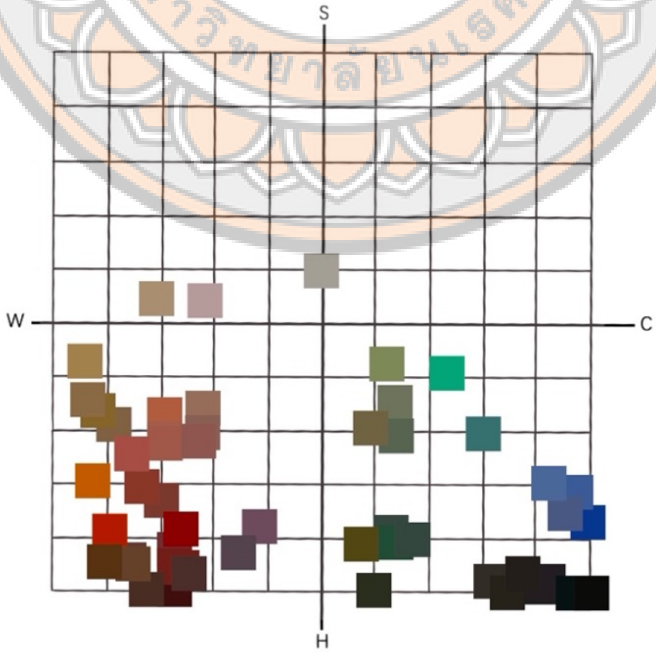


Figure 50 CA-3(A)

As can be seen through the color chart, after lowering the brightness of the original color chart, it is precisely the opposite of the color chart with a brightness of +100. The colors in the SW and SC zones move downward to the lower zones, and more than 90% of the colors are distributed in the HW and HC zones, and some intermediate colors have appeared. The color chart shows an apparent darkening effect; the visual impact is weakened, and the color contrast is reduced.

Use the tool B, The calculation and statistics of color coordinates are as follows:

Table 16 C3 Coordinate Calculation Table

Color NO.	C	M	Y	K	X coord	Y coord
W2	42	36	40	0	64	66
W3	37	40	33	0	66	70
W1	42	45	55	0	70	61
R6	51	58	65	2	70	62
R8	42	70	75	3	76	59
R7	47	68	67	4	73	62
R4	56	65	65	8	67	62
R3	56	80	78	26	66	57
R11	50	83	86	21	70	55
R2	57	84	75	32	64	57
Y7	46	51	72	1	72	57
Y10	46	51	72	1	72	57
Y9	50	60	90	11	71	52
Y5	57	63	74	11	67	59
Y4	47	71	69	6	73	61
R12	63	75	75	35	60	56
R10	67	77	79	46	58	54
R1	54	90	89	38	66	53
R9	50	100	100	28	72	54
R5	66	89	88	62	58	51
G1	73	68	63	0	64	69
G7	58	42	71	1	66	58
G6	64	52	65	4	63	63
G9	72	56	70	12	60	61
G4	62	59	78	13	65	57
Y2	36	72	100	1	82	52
Y1	42	94	100	7	80	56
Y3	62	71	83	32	62	54
Y8	62	76	96	43	62	50
Y6	67	78	78	46	58	54
P2	53	70	65	9	69	62
B3	77	52	56	4	57	68

B5	75	62	23	0	53	86
B4	79	67	39	1	57	78
B2	82	28	26	0	40	81
B1	97	88	15	0	52	93
G2	82	60	82	31	56	56
G8	70	64	100	34	61	50
G5	78	65	73	31	56	58
G3	78	71	87	54	54	51
P4	54	77	72	6	71	63
P3	67	73	56	13	62	67
P1	72	73	61	24	58	63
BL3	76	75	76	51	54	54
BL2	80	76	81	59	53	53
BL7	81	80	76	61	52	54
BL5	83	83	73	60	52	56
BL4	81	77	81	61	53	53
BL1	91	82	80	69	50	54
BL6	88	84	86	75	51	52

Tool B analysis of the colors in the color chart is shown in CA-3(B):

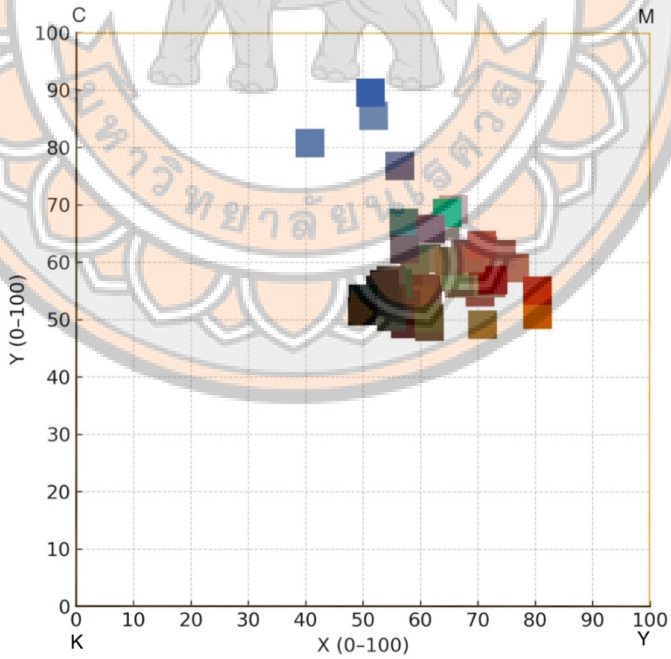


Figure 51 CA-3(B)

The color distribution in the diagram exhibits distinct clustering and displacement patterns: the upper color blocks, dominated by high C values, cluster toward the top of

the diagram, forming a cool-toned region leaning toward blue and cyan. As C values decrease and the proportions of M and Y gradually increase, colors converge toward the center and right side of the diagram, forming a dense cluster dominated by browns, grayish-browns, and low-saturation warm colors. The few reddish and orange hues on the right correspond to higher M and Y values. Overall, colors transition gradually from cool tones with high C values to warm tones with high M/Y values, exhibiting a concentrated tendency centered around neutral and low-luminance hues.

4.3.3 Analysis of contrast changes

1) Contrast +100

Adjust the contrast of the original color chart to +100 to get the following color chart C4:

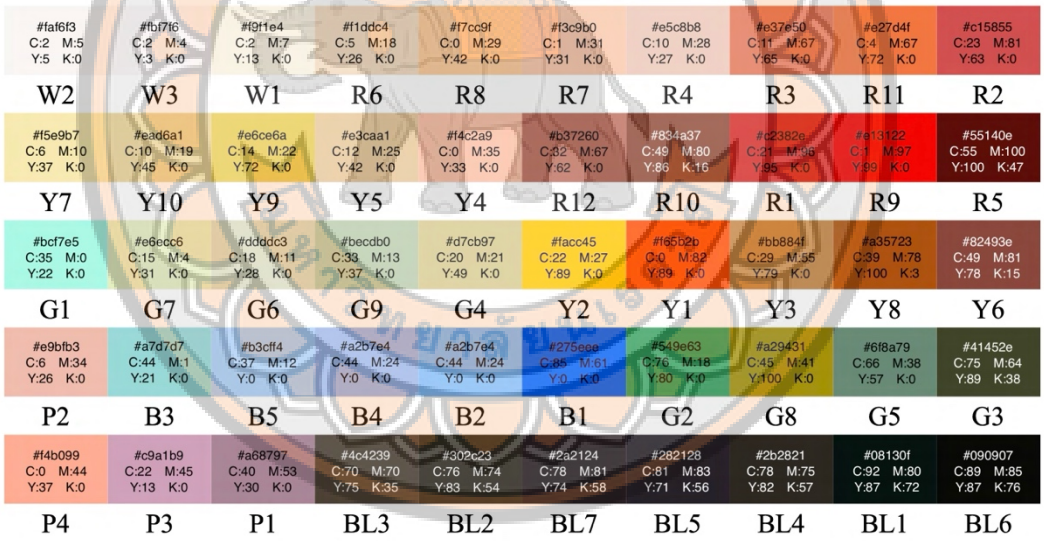


Figure 52 C4

Use the tool A, analysis of the colors in the color chart is shown in CA-4(A):

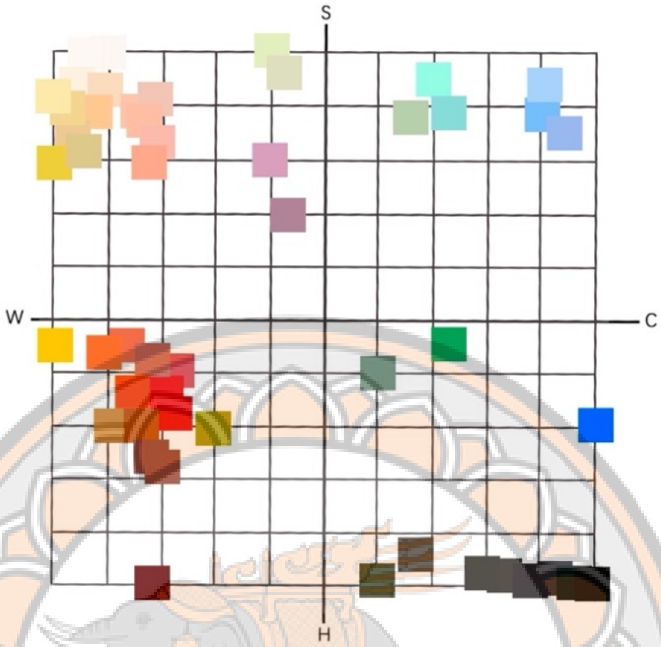


Figure 53 CA-4(A)

The color chart shows that the colors are distributed in the edge areas of the four zones, more colors are in the four corners of the position, and the colors in the HW and HC zones become more saturated relative to the original color chart. This is caused by the contrast enhancement produced by the color change, which makes the color performance more intense.

Use the tool B, The calculation and statistics of color coordinates are as follows:

Table 17 C4 Coordinate Calculation Table

Color NO.	C	M	Y	K	X_coord	Y_coord
W2	2	5	5	0	83	58
W3	2	4	3	0	78	67
W1	2	7	13	0	91	41
R6	5	18	26	0	90	47
R8	0	29	42	0	100	41
R7	1	31	31	0	98	51
R4	10	28	27	0	85	58
R3	11	67	65	0	92	55
R11	4	67	72	0	97	50
R2	23	81	63	0	86	62

Y7	6	10	37	0	89	30
Y10	10	19	45	0	86	39
Y9	14	22	72	0	87	33
Y5	12	25	42	0	85	47
Y4	0	35	33	0	100	51
R12	32	67	62	0	80	61
R10	49	80	86	16	72	56
R1	21	96	95	0	90	55
R9	1	97	99	0	99	50
R5	55	100	100	47	66	51
G1	35	0	22	0	39	61
G7	15	4	31	0	70	38
G6	18	11	28	0	68	51
G9	33	13	37	0	60	55
G4	20	21	49	0	78	46
Y2	22	27	89	0	84	36
Y1	0	82	89	0	100	48
Y3	29	55	79	0	82	52
Y8	39	78	100	3	81	53
Y6	49	81	78	15	71	58
P2	6	34	26	0	91	61
B3	44	1	21	0	33	68
B5	37	12	0	0	24	100
B4	44	24	0	0	35	100
B2	44	24	0	0	35	100
B1	85	61	0	0	42	100
G2	76	18	80	0	56	54
G8	45	41	100	0	76	46
G5	66	38	57	0	59	65
G3	75	64	89	38	58	52
P4	0	44	37	0	100	54
P3	22	45	13	0	73	84
P1	40	53	30	0	67	76
BL3	70	70	75	35	58	56
BL2	76	74	83	54	55	52
BL7	78	81	74	58	53	55
BL5	81	83	71	56	53	56
BL4	78	75	82	57	54	52
BL1	92	80	87	72	50	52
BL6	89	85	87	76	51	52

Tool B analysis of the colors in the color chart is shown in CA-3(B):

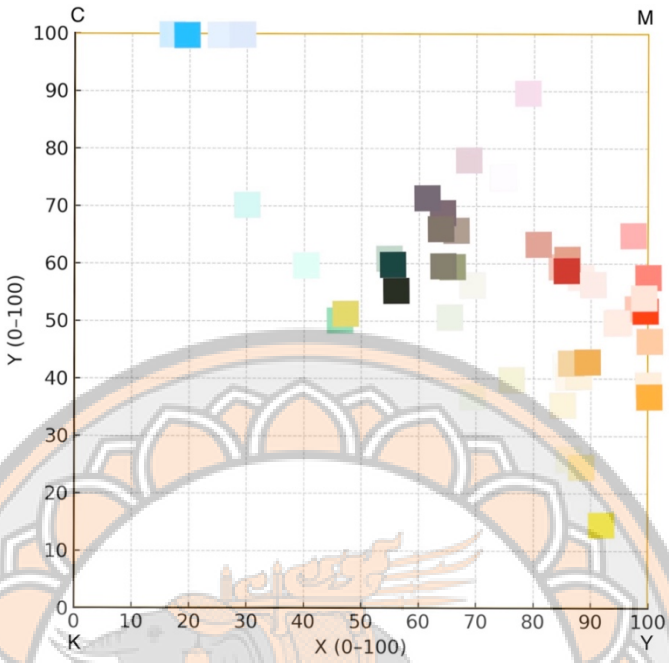


Figure 54 CA-4(B)

The color distribution in the diagram progresses from high C toward high M and Y: the top section concentrates on cool colors dominated by high C values. As C, M, and Y values approach each other while K increases, color blocks cluster toward the center to form neutral tones. As M and Y increase while C decreases, colors shift toward the right and lower right, forming a warm color zone. The overall structure exhibits a gradient transition from cool to warm and from light to medium brightness.

2) Contrast -50

As the color will be blurred after contrast -100 in Photoshop, which affects the judgment of the color, here we only reduce the contrast to -50 to make sure that it does not affect the visual effect of the color, and get the following color chart C5:

Figure 55 C5

Use the tool A, analysis of the colors in the color chart is shown in CA-5(A):

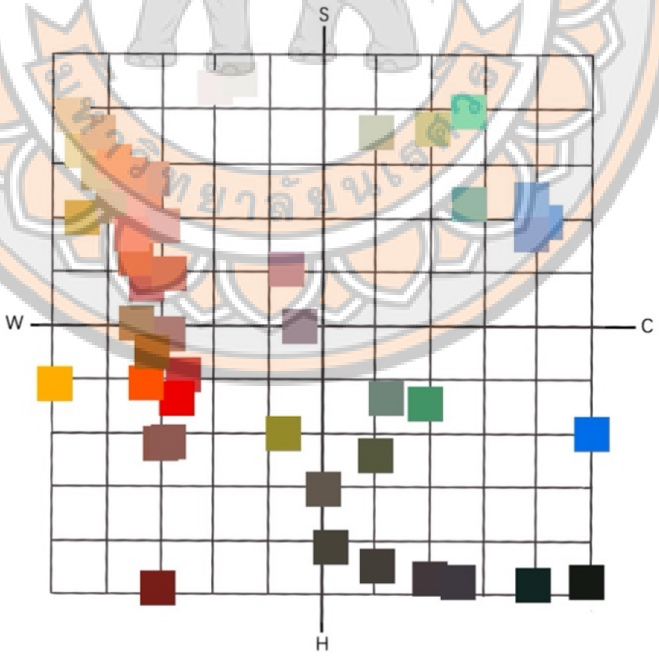


Figure 56 CA-5(A)

As can be seen through the color chart, comparing the original color chart and the color chart with contrast +100, the colors in this color chart gradually converge to the middle of the numerical axis, the intermediate colors increase, the brightness decreases, the colors in the SW zone and the HW zone are gradually connected, and the colors in the HC zone are also converging progressively to the middle area, with a large number of gray-toned colors appearing.

Use the tool B, The calculation and statistics of color coordinates are as follows:

Table 18 C5 Coordinate Calculation Table

Color NO.	C	M	Y	K	X coord	Y coord
W2	12	11	14	0	68	62
W3	8	14	10	0	75	69
W1	13	18	28	0	78	53
R6	19	33	36	0	78	59
R8	10	44	43	0	90	56
R7	15	44	38	0	85	61
R4	24	41	33	0	76	66
R3	33	60	53	0	77	64
R11	25	62	58	0	83	60
R2	39	66	50	0	75	68
Y7	16	24	46	0	81	47
Y10	25	33	49	0	77	54
Y9	29	34	61	0	77	51
Y5	28	38	45	0	75	59
Y4	13	47	39	0	87	61
R12	46	57	52	0	70	66
R10	55	64	64	7	67	63
R1	39	78	66	1	78	64
R9	26	92	99	0	88	54
R5	52	87	87	28	69	55
G1	48	0	36	0	43	57
G7	29	13	44	0	66	49
G6	33	25	37	0	65	61
G9	46	28	42	0	60	64
G4	35	34	50	0	71	58
Y2	6	44	81	0	95	38
Y1	7	72	78	0	96	50
Y3	44	52	61	0	72	61
Y8	48	61	82	5	73	56
Y6	56	64	58	5	67	66
P2	22	46	37	0	79	65

B3	53	19	31	0	49	70
B5	48	30	20	0	51	80
B4	53	38	10	0	48	90
B2	55	35	0	0	39	100
B1	78	54	0	0	41	100
G2	68	37	61	0	59	63
G8	52	47	78	1	70	56
G5	61	45	49	0	61	68
G3	68	58	69	13	61	61
P4	12	54	40	0	89	62
P3	40	49	29	0	66	75
P1	50	51	39	0	64	72
BL3	66	61	62	10	62	64
BL2	71	65	70	24	59	59
BL7	73	71	65	28	57	61
BL5	74	71	62	25	57	63
BL4	72	66	68	25	58	60
BL1	87	71	76	50	52	56
BL6	83	77	83	63	52	52

Tool B analysis of the colors in the color chart is shown in CA-5(B):

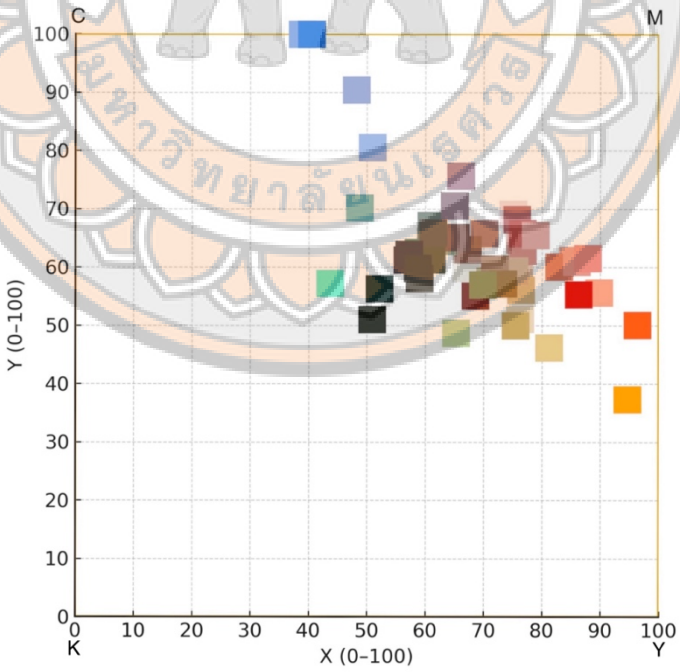


Figure 57 CA-5(B)

This diagram illustrates a structural distribution progressing from high C values toward high M and Y values: Color blocks near the top are dominated by high C, forming a concentrated area of cool colors. When C, M, and Y values converge and K values are moderate, color blocks cluster toward the center of the diagram, appearing as low-saturation gray-green and gray-brown tones. As M and Y increase while C decreases, colors shift toward the right, forming a warm-color zone encompassing orange, red, and related hues. The overall pattern demonstrates a gradient transition from high C to high M/Y, alongside a continuous shift from cool to warm tones.

4.3.4 Analysis of Hue Changes

Most of the colors in the above five color charts can be done using original mineral pigments and modulation of mineral pigments, which is suitable for painting or producing artworks created using pigments. To make the use of Mogao Cave mural colors more extensive, for example, in the use of computer design and painting, and to enrich the colors in the color charts, the hue in the color charts is hereby changed by extracting the hue of the charts of +90, -90, respectively, ±180 of the color table to get new colors to analyze the change of color relationship of Mogao Cave murals.

1) Color Hue +90

Adjust the hue of the original color table to +90 to get the following color chart C6:

Figure 58 C6

Use the tool A, analysis of the colors in the color chart is shown in CA-6(A):

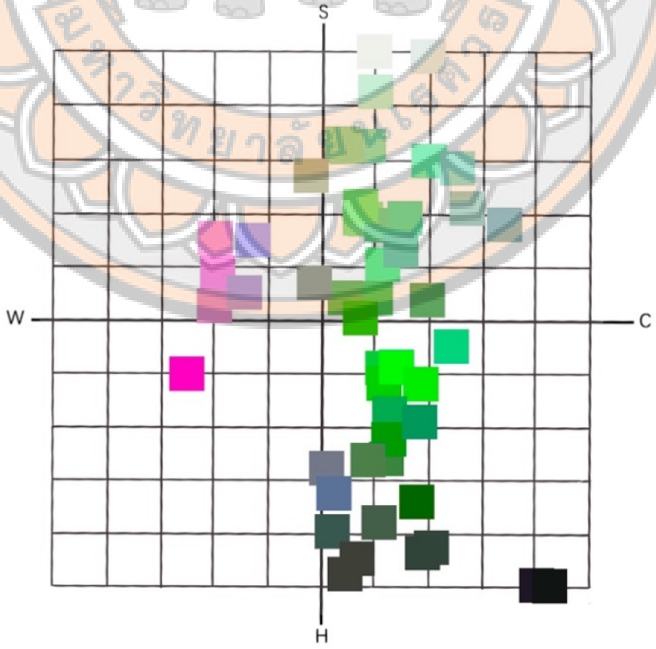


Figure 59 CA-6(A)

As can be seen through the color chart, compared with the original color chart, due to the change of hue, the overall color has changed, the whole is concentrated in the middle area of the numerical axis, the contrast between cold and warm becomes weaker, and the color is divided into two parts, 90% is distributed in the middle of the HC zone and the SC zone, and 10% is distributed in the middle part of the SW zone and the HW zone. The color shows a harmonious but hierarchical character.

Use the tool B, The calculation and statistics of color coordinates are as follows:

Table 19 C6 Coordinate Calculation Table

Color NO.	C	M	Y	K	X coord	Y coord
W2	15	6	11	0	53	66
W3	10	5	11	0	62	58
W1	29	0	28	0	49	51
R6	43	0	44	0	51	49
R8	51	0	61	0	54	46
R7	45	0	54	0	55	45
R4	41	5	46	0	55	50
R3	60	4	77	0	57	45
R11	69	0	100	0	59	41
R2	59	17	78	0	62	49
Y7	46	0	43	0	48	52
Y10	53	0	52	0	50	50
Y9	64	0	64	0	50	50
Y5	54	0	55	0	50	50
Y4	46	0	56	0	55	45
R12	62	24	70	0	60	55
R10	75	40	88	2	62	56
R1	67	10	98	0	62	44
R9	69	0	100	0	59	41
R5	84	50	100	15	60	54
G1	38	35	0	0	48	100
G7	41	0	27	0	40	60
G6	40	14	31	0	53	64
G9	46	24	27	0	53	72
G4	55	10	49	0	52	57
Y2	63	0	91	0	59	41
Y1	65	0	100	0	61	39
Y3	72	14	82	0	57	51
Y8	81	22	100	0	60	51
Y6	72	41	81	2	62	58
P2	42	4	50	0	56	48
B3	38	44	8	0	58	91

B5	13	47	0	0	78	100
B4	19	52	1	0	74	99
B2	13	47	0	0	78	100
B1	26	82	0	0	76	100
G2	71	55	31	0	55	80
G8	80	25	77	0	56	58
G5	62	53	40	0	60	74
G3	80	59	68	19	56	62
P4	46	0	61	0	57	43
P3	37	28	45	0	66	59
P1	49	38	48	0	64	64
BL3	76	56	73	16	58	60
BL2	79	65	74	33	55	57
BL7	76	69	73	37	56	57
BL5	73	75	69	38	56	58
BL4	79	66	75	38	55	56
BL1	86	89	68	57	52	58
BL6	87	80	81	68	51	53

Tool B analysis of the colors in the color chart is shown in CA-6(B):

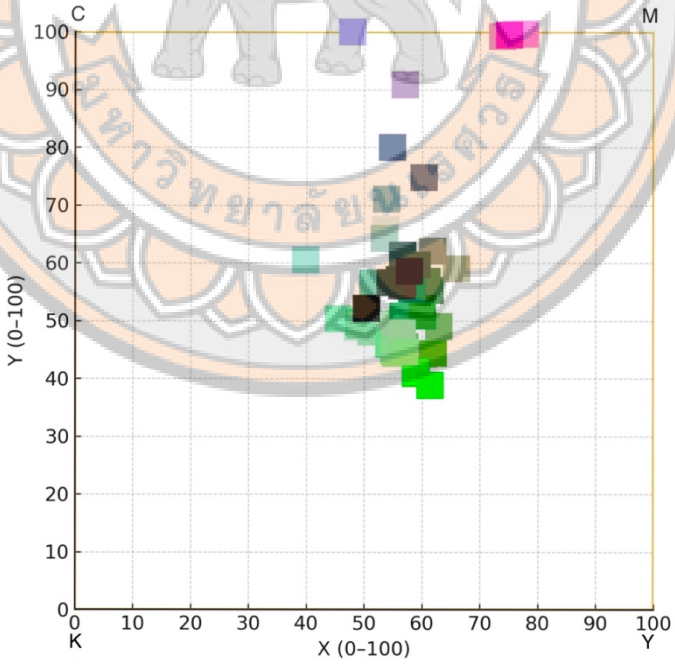


Figure 60 CA-6(B)

The color distribution in this diagram exhibits a trend shifting from high C values toward higher M and Y values: the top color blocks are dominated by high C and high

M, resulting in a concentration of cool tones and highly saturated colors. When C, M, and Y values converge and K remains moderate, colors cluster in the central region, manifesting as low-saturation neutral hues like gray-green and gray-blue. As the proportion of Y increases while C and M decrease, colors shift toward the lower right, forming a group of higher-luminance green and yellow-green blocks. The overall structure reveals a transition from cool colors to greens and warm colors, alongside a hierarchical progression from high luminance to medium luminance.

2) Color Hue -90

Adjust the hue of the original color chart to -90 to get the following color chart C7:

Figure 61 C7

An analysis of the colors in the color chart is shown in CA-7:

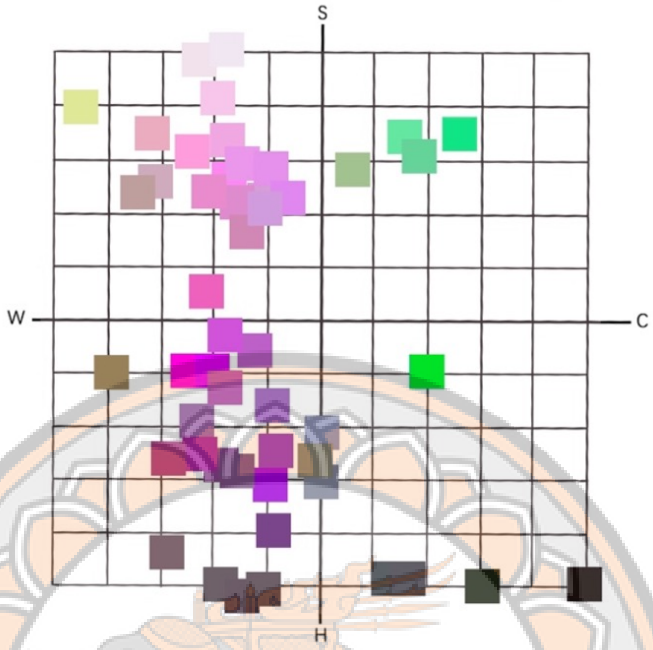


Figure 62 CA-7(A)

As can be seen through the color chart, this color chart and the color chart of hue +90 show opposite trends in color distribution. The overall color is still concentrated in the middle area of the numerical axis, with 90% distributed in the middle region of the SW and HW zones and 10% distributed in the HC and SC zones, but distributed at both ends of the spectrum.

Use the tool B, The calculation and statistics of color coordinates are as follows:

Table 20 C7 Coordinate Calculation Table

Color NO.	C	M	Y	K	X coord	Y coord
W2	8	14	6	0	71	79
W3	8	11	1	0	60	95
W1	8	28	0	0	78	100
R6	16	42	0	0	72	100
R8	22	51	0	0	70	100
R7	23	46	0	0	67	100
R4	25	42	0	0	63	100
R3	43	67	0	0	61	100
R11	43	71	0	0	62	100
R2	53	68	0	0	56	100
Y7	11	47	0	0	81	100
Y10	18	53	0	0	75	100

Y9	20	68	0	0	77	100
Y5	22	53	0	0	71	100
Y4	25	48	0	0	66	100
R12	51	66	11	0	60	91
R10	63	80	26	0	63	85
R1	60	80	0	0	57	100
R9	66	85	0	0	56	100
R5	83	100	39	2	62	82
G1	18	4	48	0	74	31
G7	14	40	14	0	79	79
G6	26	36	20	0	68	76
G9	33	40	32	0	69	70
G4	27	53	13	0	71	86
Y2	24	79	0	0	77	100
Y1	50	79	0	0	61	100
Y3	40	74	0	0	65	100
Y8	49	90	0	0	65	100
Y6	64	75	30	0	62	82
P2	27	45	0	0	63	100
B3	42	16	49	0	61	54
B5	48	0	47	0	49	51
B4	52	1	49	0	49	52
B2	56	0	58	0	51	49
B1	67	0	86	0	56	44
G2	49	49	65	0	70	60
G8	49	85	33	0	71	80
G5	55	48	53	0	65	66
G3	68	74	62	23	60	63
P4	31	51	0	0	62	100
P3	48	40	16	0	54	85
P1	65	47	31	0	55	78
BL3	69	73	53	11	61	69
BL2	74	76	63	31	57	61
BL7	80	75	64	34	55	61
BL5	81	70	67	34	54	60
BL4	75	77	63	33	56	61
BL1	82	72	92	61	53	50
BL6	82	82	84	70	52	52

Tool B analysis of the colors in the color chart is shown in CA-7(B):

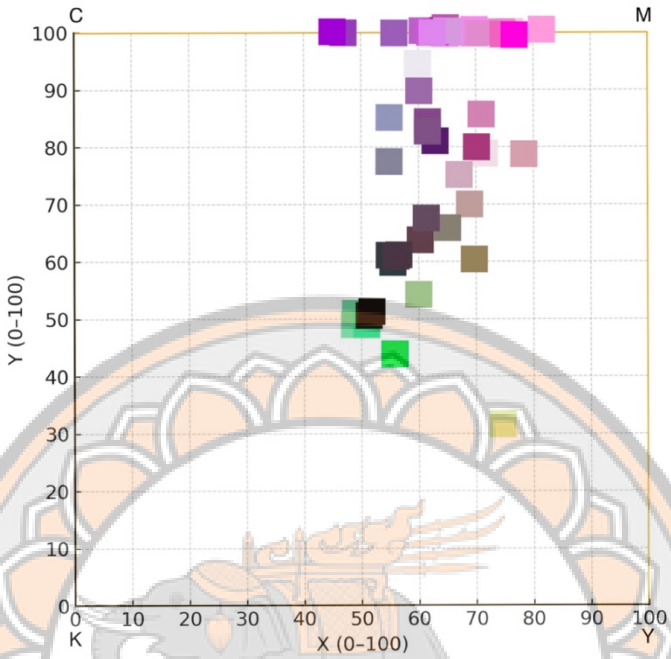


Figure 63 CA-7(B)

The colors in the diagram exhibit a structural progression from high C and M values toward lower C and higher Y values. The top color blocks are distinctly concentrated in the high C and high M regions, forming a series of bright purples, pinks, and cool tones. As C and M values decrease and Y increases, the colors gradually shift toward the center of the diagram, forming groups of less saturated grayish-purples, grayish-browns, and neutral tones. As values continue to shift and the proportion of Y or K increases, the color blocks move toward the lower part of the diagram, revealing green and yellow-toned hues. The overall color distribution demonstrates a transition from cool tones dominated by high C/M values to neutral and warm green tones characterized by reduced C/M and increased Y/K participation, exhibiting a distinct gradient trend and structural layering.

3) Hue ± 180

Adjust the hue of the original color chart to ±180 to obtain the following color chart C8:

Figure 64 C8

An analysis of the colors in the color chart is shown in CA-8:

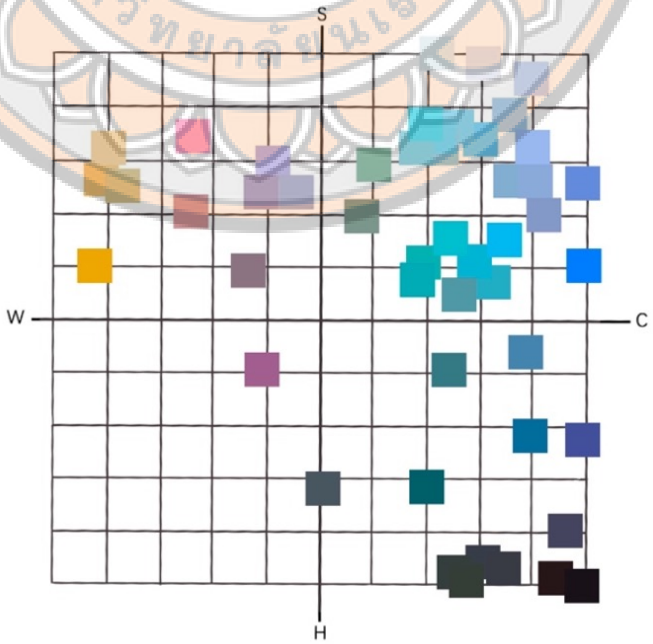


Figure 65 CA-8

Through the analysis of the color chart, it can be seen that, compared with the color chart of hue ± 90, the overall color in this color chart produces a change of more than 90% of the colors are distributed in the SW zone, the SC zone and the HC zone, which indicates that the colors show a high degree of sharpness and low saturation effect.

Use the tool B, The calculation and statistics of color coordinates are as follows:

Table 21 C8 Coordinate Calculation Table

Color NO.	C	M	Y	K	X_coord	Y_coord
W2	12	10	4	0	54	85
W3	13	4	6	0	43	74
W1	25	15	2	0	40	95
R6	39	17	9	0	40	86
R8	50	11	5	0	24	92
R7	47	7	12	0	29	82
R4	43	15	16	0	42	78
R3	66	20	24	0	40	78
R11	69	15	20	0	34	81
R2	68	16	34	0	42	71
Y7	42	26	0	0	38	100
Y10	49	30	4	0	41	95
Y9	64	44	0	0	41	100
Y5	50	26	12	0	43	86
Y4	49	7	12	0	28	82
R12	66	32	35	0	50	74
R10	78	49	45	1	54	73
R1	76	16	36	0	41	72
R9	72	7	26	0	31	75
R5	91	57	58	10	53	69
G1	5	47	5	0	91	91
G7	33	32	0	0	49	100
G6	36	31	13	0	55	84
G9	37	40	15	0	60	84
G4	52	39	10	0	49	90
Y2	79	51	0	0	39	100
Y1	72	13	7	0	22	92
Y3	72	45	23	0	49	84
Y8	84	56	28	0	50	83
Y6	76	48	46	1	55	73
P2	47	9	20	0	38	74
B3	27	48	33	0	75	69
B5	13	24	42	0	84	47
B4	24	26	47	0	75	52

B2	15	29	54	0	85	45
B1	16	38	91	0	89	37
G2	49	70	28	0	67	81
G8	28	74	17	0	76	86
G5	55	57	41	0	64	73
G3	80	75	53	16	57	69
P4	53	0	15	0	22	78
P3	51	21	40	0	54	64
P1	56	35	44	0	59	67
BL3	76	64	56	12	58	67
BL2	80	72	64	31	55	62
BL7	78	68	74	38	55	57
BL5	78	68	73	37	55	57
BL4	80	73	65	34	55	61
BL1	76	85	77	64	54	53
BL6	85	86	76	66	52	55

Tool B analysis of the colors in the color chart is shown in CA-8(B):

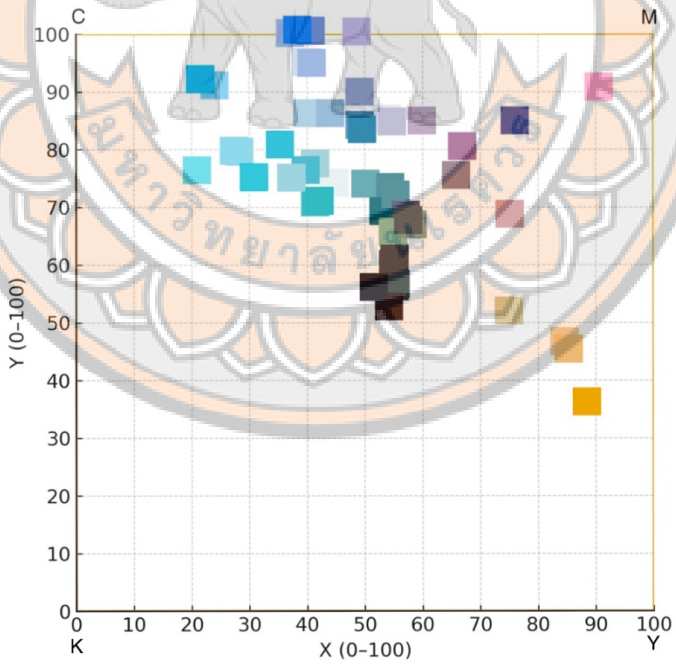


Figure 66 CA-7(B)

The colors in the diagram exhibit a gradual progression from high C values toward higher Y and M values. The color blocks in the upper and upper-left regions are

dominated by high C, resulting in bright blues, cyan, and violet hues. As C values decrease and the proportions of M and Y increase, the colors shift toward the center-right area of the diagram, forming a group of desaturated gray-blues, gray-purples, and neutral tones. As Y increases and C decreases further, the color blocks extend noticeably toward the lower right, introducing warm tones like yellow and orange. The overall distribution reflects a continuous transition in CMYK values from “high C dominance” to “high M/Y dominance,” with the introduction of K values creating a low-luminance cluster in the central region.

4.4 Analysis of Techniques

The primary color techniques in the Mogao Cave murals are the Shading and Highlighting Techniques of Hinduka and the flat dyeing technique. The one that has the most characteristics of the color of the Mogao Cave murals in the Northern Dynasties and Tang Dynasty is the Shading and Highlighting Techniques of Hinduka, which is a dyeing technique that expresses the picture by layered dyeing and transitioning from dark to light colors (see 2.1.4 for details), in which the change of the color depth is caused by the different proportions of gelatin and water, the color scale is used here to show specific color change effects, as shown in the table below:

Figure 67 Color Scale

Therefore, this section focuses on analyzing the Shading and Highlighting Techniques of Hinduka's color-layered dyeing and color shade changes to express the uniqueness of Mogao Cave mural painting colors in terms of technique. After analyzing the characteristics and commonalities of colors through the analysis of brightness, contrast, and hue changes in the previous chapter, in this chapter, we will randomly extract the data from the eight color analysis charts CA1-CA8 obtained from the prior analysis and use Photoshop to simulate the changes of the color layered dyeing in the mural paintings and analyze the layered dyeing effects under different brightness, contrast, and hue. By analyzing the layered dyeing effect, the color diversity of Mogao Cave murals can be explored from the technical layer, and a more comprehensive understanding of how colors can achieve specific visual effects through layered dyeing and hierarchical changes can be achieved.

4.4.1 Original Color Layered Dyeing Analysis

First, the CA-1 color analysis chart was used for color extraction. When extracting the color in the original color chart, respectively, SW, SC, HW, and HC 4 zones as the primary color-taking interval, the color of each interval with other zones of the color layered dyeing, the process of color-taking is shown in the following figure:

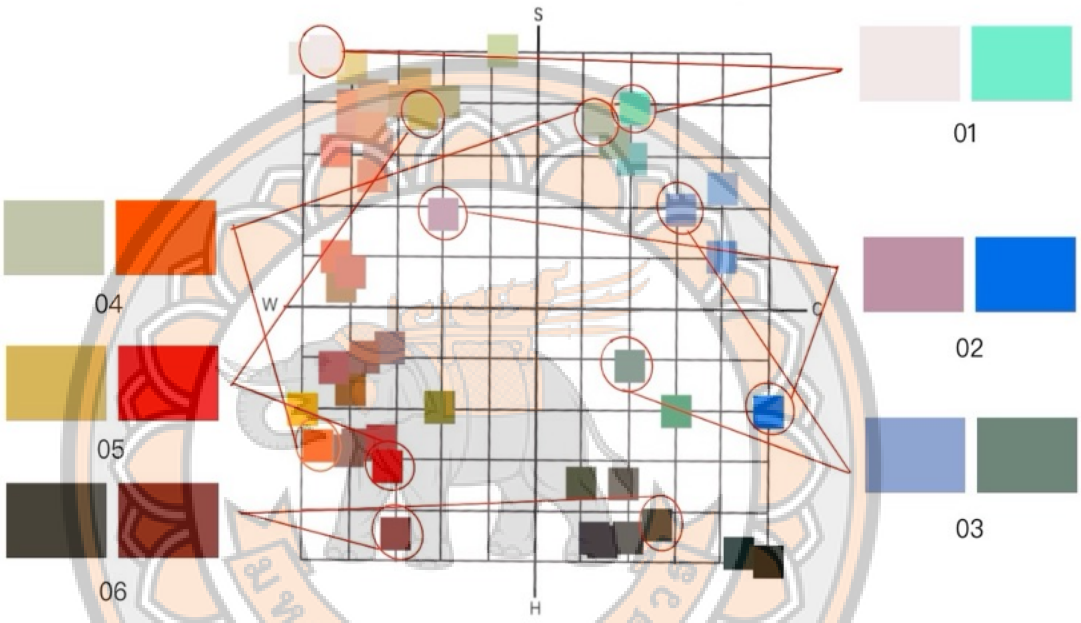


Figure 68 CA-1 Taking Color

From the four zones, six groups of colors are randomly taken out, which are:

Group 01: C1-W3 C1-G1

Group 02: C1-P3 C1-B1

Group 03: C1-B4 C1-G5

Group 04: C1-G6 C1-Y1

Group 05: C1-Y9 C1-R9

Group 06: C1-BL2 C1-R5

The six groups of colors will be exchanged for layered dyeing (for example, in group 01, the first C1-W3 as the base color, overlaying C1-G1, and then C1-G1 as the base color, overlaying C1-W3). Then, the transparency of the results will be adjusted to 35% and 65%, respectively, simulating the change in color scale produced by adding water and gelatin to the color; all of the following layered dyeings follow this method. The results obtained are shown in Figure CT-1:

Figure 69 CT-1

4.4.2 Brightness Change Layered Dyeing Analysis

1) Brightness +100

Use the CA-2 color analysis chart for color extraction; in extracting the colors in this color chart, respectively, SW, SC, HW, and HC 4 zones as the main color extraction zones due to the high brightness so that the distribution of colors in the SW zone and SC zone is more, SW zone distribution of colors is the most. Therefore, firstly, a group of colors of the same color zone is extracted in the SW zone. Two colors are extracted in the SW and SC zones, respectively, and the other three are extracted from adjacent color zones for layered dyeing. The color extraction process is shown in the following figure:

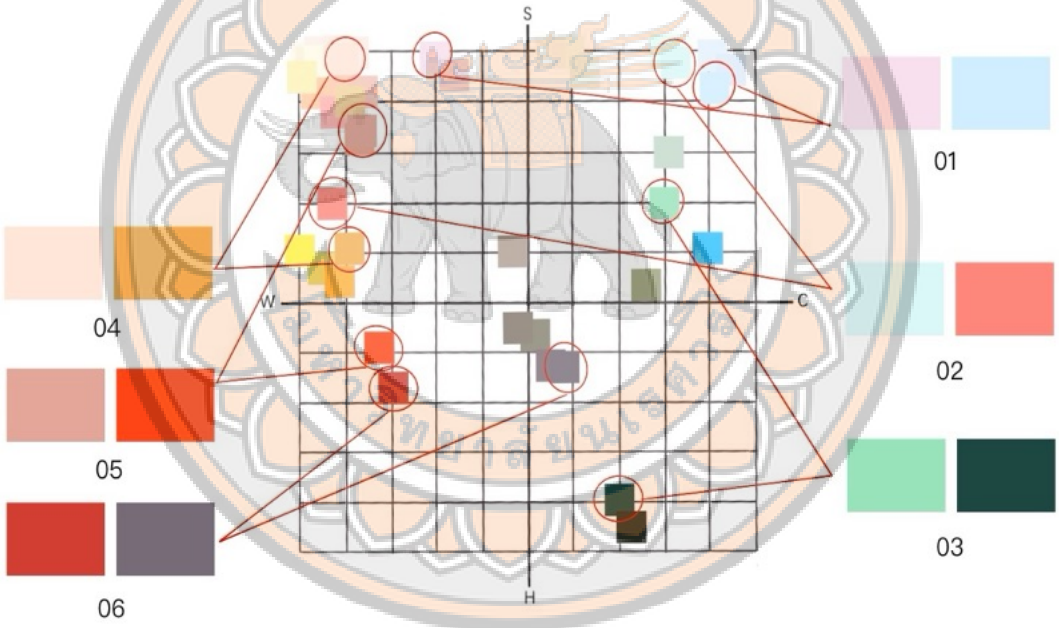


Figure 70 CA-2 Taking Color

From the four zones, six groups of colors were randomly taken out as follows:

Group 01: C2-P3 C2-B5

Group 02: C2-B3 C2-R1

Group 03: C2-G2 C2-BL1

Group 04: C2-P4 C2-Y8

Group 05: C2-R12 C2-R9

Group 06: C2-R5 C2-BL5

The six groups of colors were exchanged layered dyeing and transparency adjustments; the results are shown in Figure CT-2:

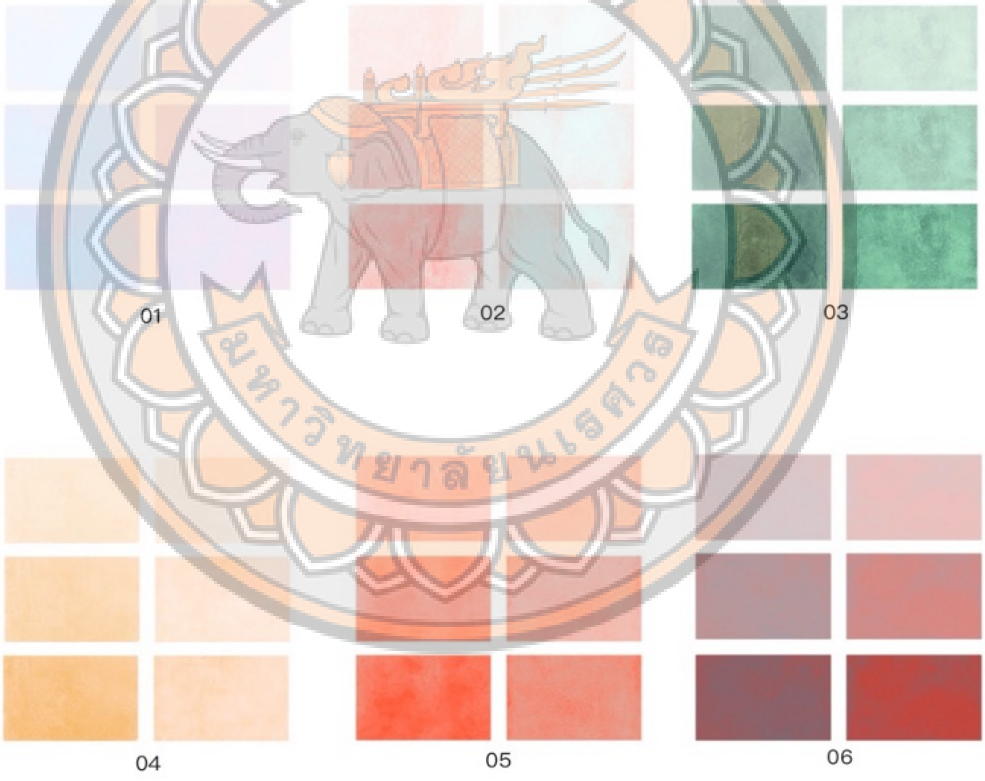


Figure 71 CT-2

2) Brightness-100

Using the CA-3 color analysis chart for color extraction, when extracting the colors in the color chart, due to the low brightness, most of the colors are distributed in the SW and HW zones, so the two zones of SW-HW and SC-HC are taken as the main color extraction zones, respectively. Firstly, two colors with the same color zone are extracted in HW and HC zones, respectively, and the other four colors are extracted in SW-HW and SC-HC zones. The color extraction process is shown in the figure below:

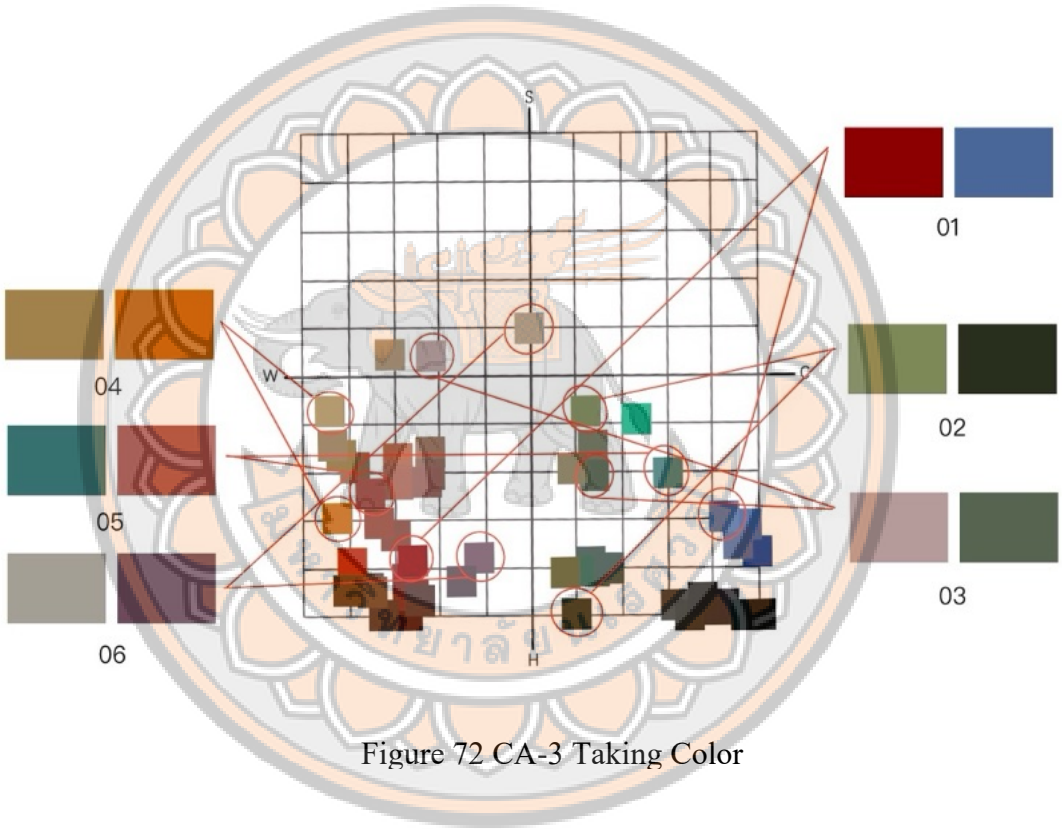


Figure 72 CA-3 Taking Color

From the two zones, six groups of colors are randomly taken out, which are:

Group 01: C3-R9 C3-B5

Group 02: C3-G7 C3-BL2

Group 03: C3-W3 C3-G9

Group 04: C3-Y7 C3-Y2

Group 05: C3-B3 C3-P4

Group 06: C3-W2 C3-P3

The six groups of colors were exchanged layered dyeing and transparency adjustments, and the results are shown in Figure CT-3:

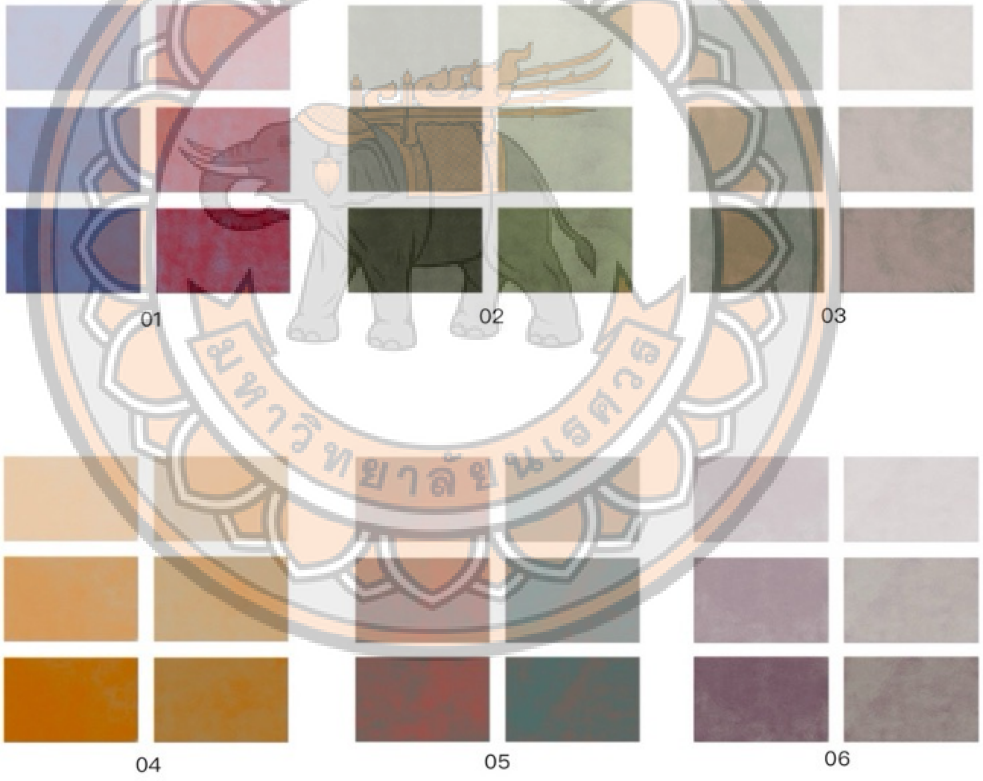


Figure 73 CT-3

4.4.3 Contrast Change Layered Dyeing Analysis

1) Contrast +100

Using the CA-4 color analysis chart for color extraction, when extracting the colors in this color chart, due to the high contrast so that most of the colors are distributed in the edge area of the four zones of the color chart, the middle distribution of color is less, so the two zones of SW-HW and SC-HC respectively as the main color extraction intervals. Three groups of colors in the SW-HW area and three groups of colors in the SC-HC area are taken, respectively. The process of taking colors is shown in the following figure:

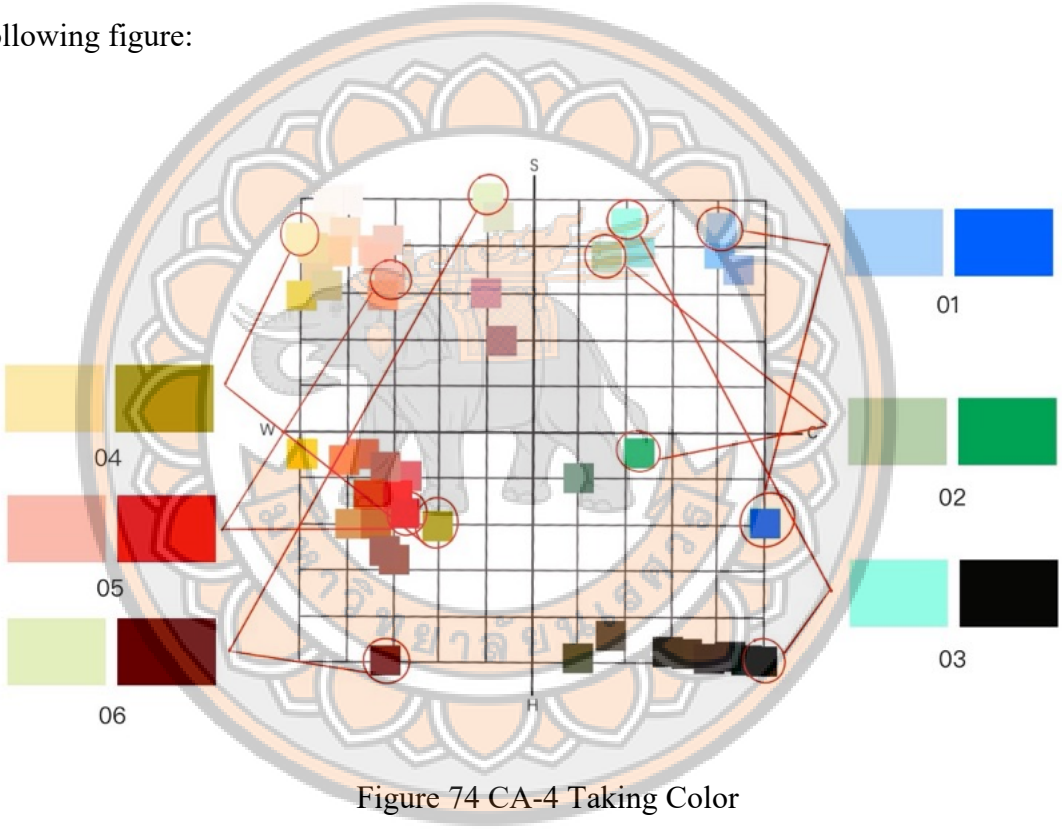


Figure 74 CA-4 Taking Color

From the two zones, six groups of colors are randomly taken out, which are:

Group 01: C4-B5 C4-B1

Group 02: C4-G9 C4-G2

Group 03: C4-G1 C4-BL6

Group 04: C4-Y7 C4-G8

Group 05: C4-Y4 C4-R9

Group 06: C4-G7 C4-R5

The six groups of colors were exchanged layered dyeing and transparency adjustments, and the results are shown in Figure CT-4:

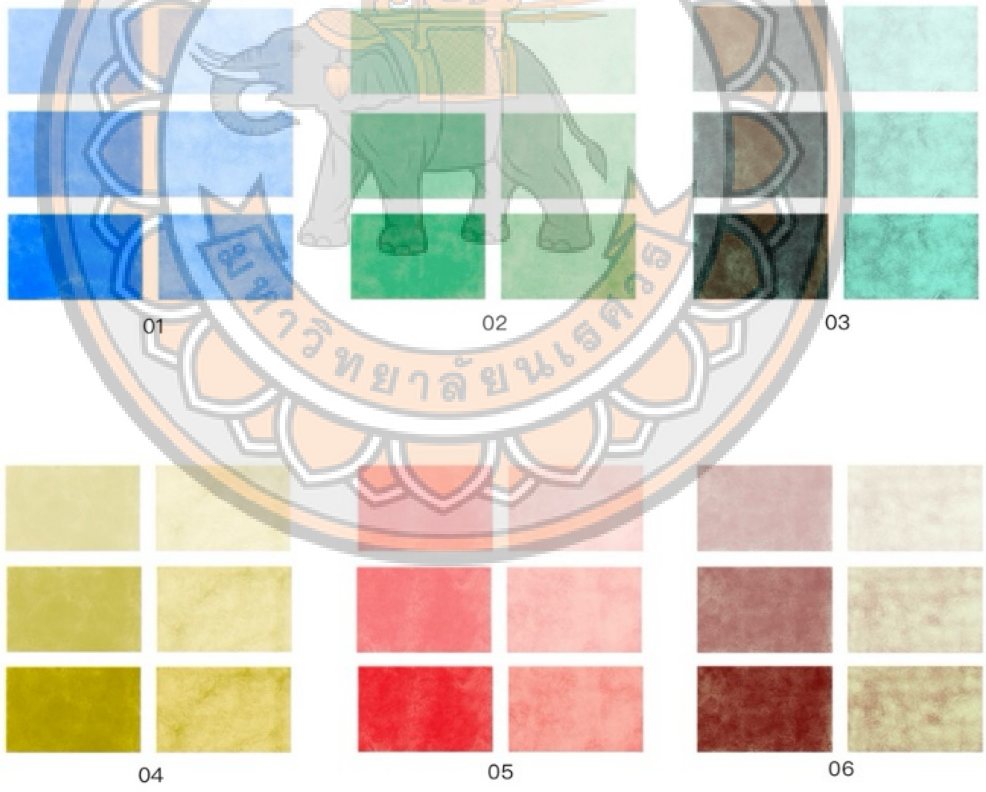


Figure 75 CT-4

02) Contrast -50

Using the CA-5 color analysis chart for color extraction, when extracting the colors in the color chart, the color distribution tends to be in the middle of the region due to the low contrast. However, the distribution of warm and cold is relatively straightforward, so the color chart still shows the SW-HW and SC-HC zones, respectively, as the main color extraction zones. 3 groups of colors in the SW-HW zone and three groups of colors in the SC-HC zone, respectively. The process of taking colors is shown in the figure below:

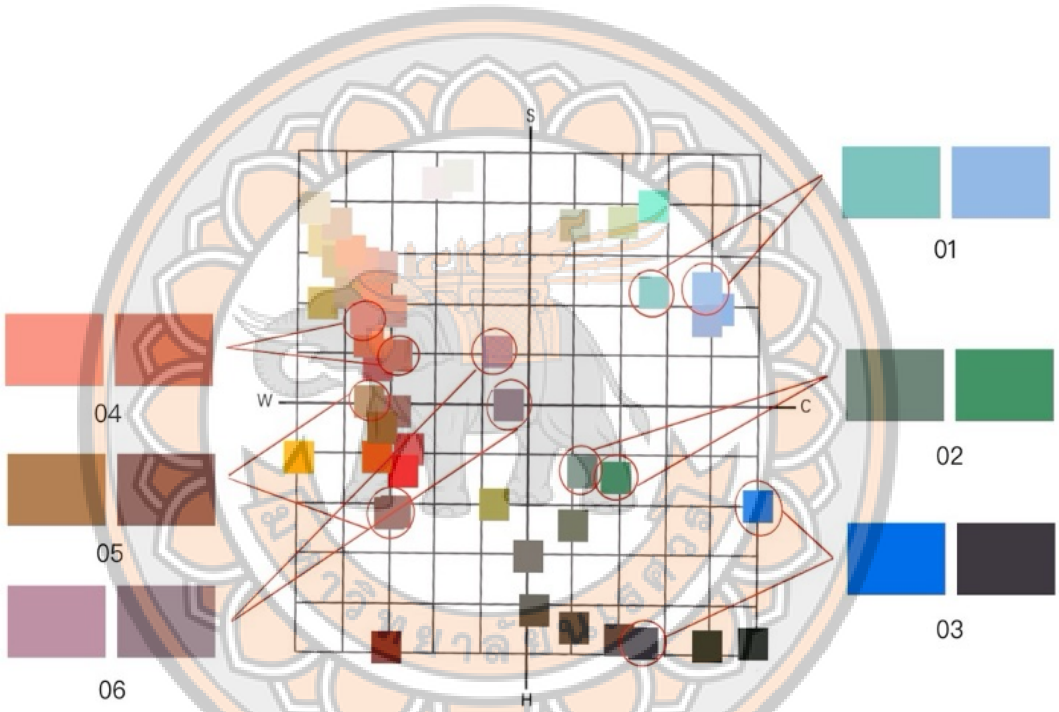


Figure 76 CA-5 Taking Color

From the two zones, six groups of colors were randomly taken out as follows:

Group 01: C5-B3 C5-B5

Group 02: C5-G5 C5-G2

Group 03: C5-B1 C5-BL5

Group 04: C5-P4 C5-R2

Group 05: C5-Y3 C5-R10

Group 06: C5-P3 C5-P1

The six groups of colors were exchanged layered dyeing and transparency adjustments, and the results are shown in Figure CT-5:

Figure 77 CT-5

4.4.4 Hue Change Layered Dyeing Analysis

01) Hue +90

Using the CA-6 color analysis chart for color extraction, when extracting the colors in this color chart, due to the change of hue, the colors are basically distributed in the middle region of the number axis and dominated by two shades, respectively, purple tone and green tone, green tone color accounts for a large proportion, the distribution in the color chart is more prominent, purple tone color all in the SW-HW zone, most of the green tone is in the SC-HC zone, and a small number of them are in the middle zone. Therefore, the two zones of SW-HW and SC-HC are the main color extraction zones. Three colors are extracted from the same color zone in SC-HC, a group of colors is extracted from the same color zone in SW-HW, and the other two colors are extracted in 2 color zones. The color extraction process is shown in the following figure:

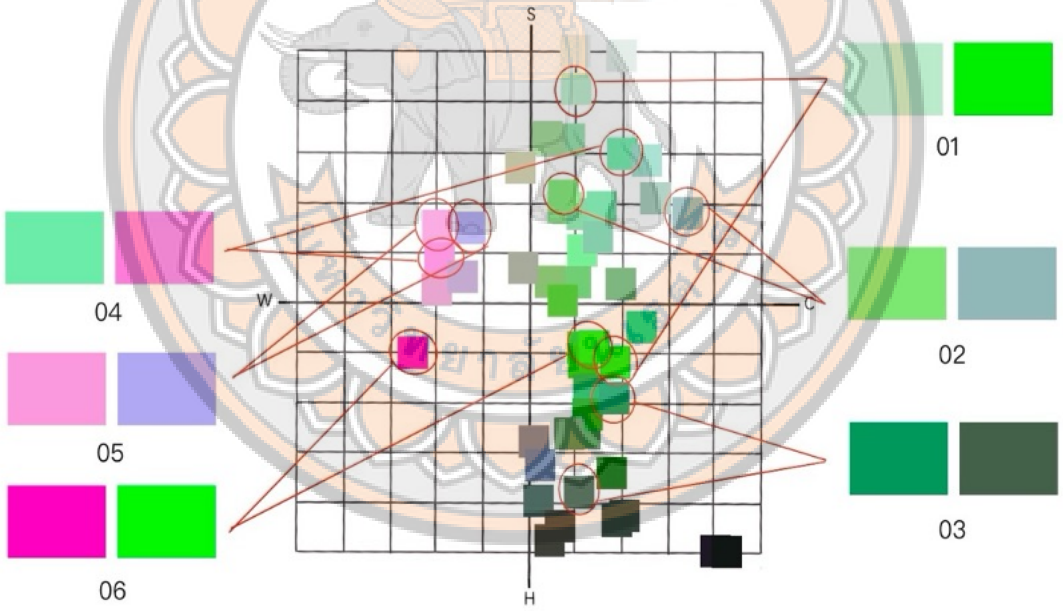


Figure 78 CA-6 Taking Color

From the two zones, six groups of colors were randomly taken out as follows:

Group 01: C6-W1 C6-Y1

Group 02: C6-R8 C6-G9

Group 03: C6-G8 C6-BL3

Group 04: C6-Y7 C6-B2

Group 05: C6-B5 C6-G1

Group 06: C6-B1 C6-Y2

6 groups of colors were exchanged layered dyeing and transparency adjustments, and the results are shown in Figure CT-6:

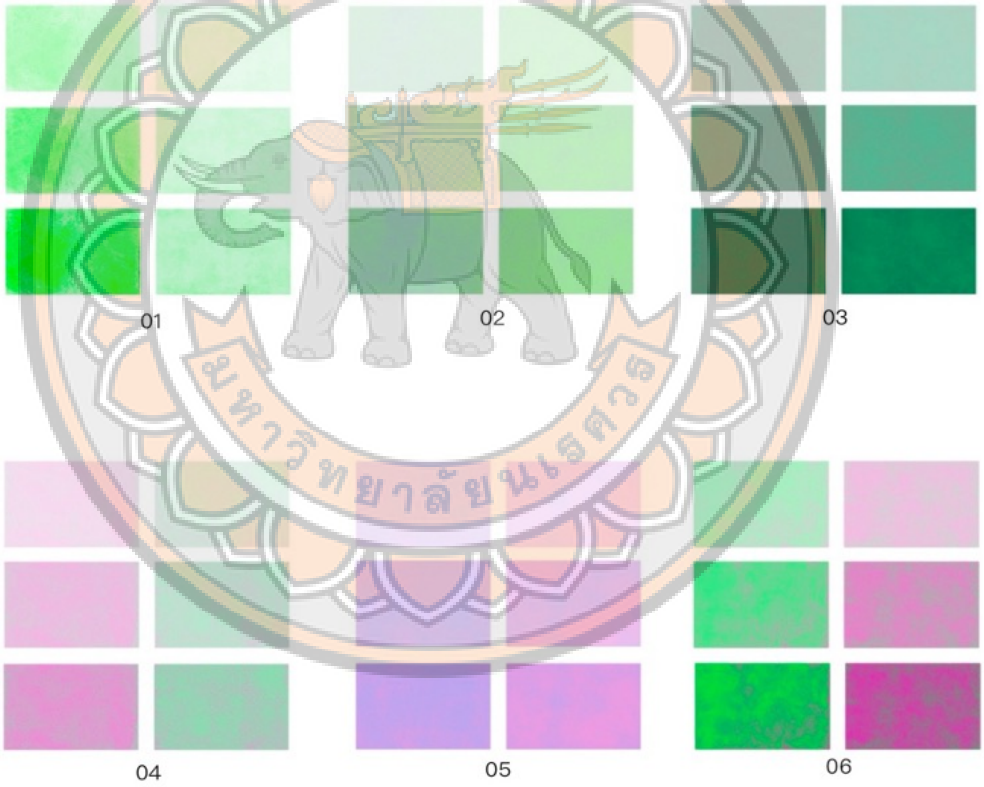


Figure 79 CT-6

02) Hue -90

Using the CA-7 color analysis chart for color extraction, the colors in this color chart are similar to those in CA-6. Due to the change of hue, the colors are distributed in the middle region of the numerical axis. They are dominated by two shades: violet tones and green tones. CA-6 is the opposite; purple tone colors account for a large proportion of the distribution in the color table, which is more prominent. Purple tone colors are all in the SW-HW area, green tone is most in the SC-HC area, and a small part is in the middle area. Therefore, SW-HW and SC-HC are the main color extraction zones. Three colors are extracted from the same color zone in the SW-HW zone, 1 group of colors is extracted from the SC-HC and middle zones, and the other two colors are extracted in 2 color zones. The color extraction process is shown in the following figure:

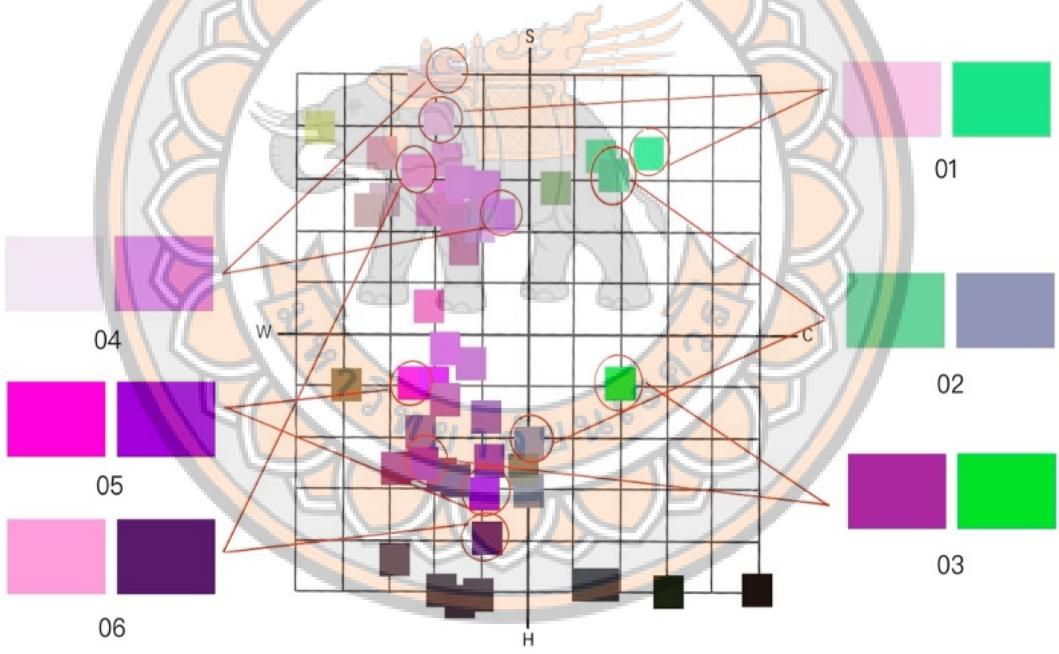


Figure 80 CA-7 Taking Color

From the two zones, six groups of colors were randomly taken out as follows:

Group 01: C7-W1 C7-B2

Group 02: C7-B4 C7-P3

Group 03: C7-Y8 C7-B1

Group 04: C7-W3 C7-P4

Group 05: C7-Y2 C7-R9

Group 06: C7-Y7 C7-R5

The six groups of colors were exchanged layered dyeing and transparency adjustments, and the results are shown in Figure CT-7:

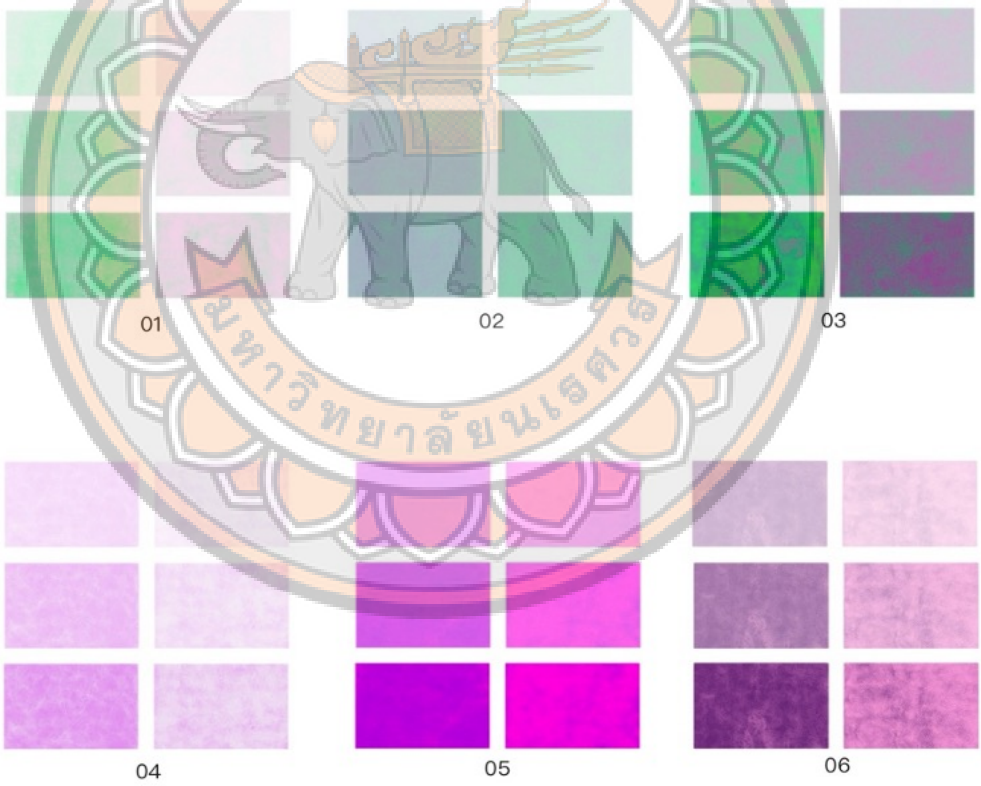


Figure 81 CT-7

03) ±180

Using the CA-8 color analysis chart for color extraction, when extracting the colors in the intrinsic color chart, similar to CA-7, the inherent color chart is mainly dominated by three tones due to the change of hue: blue tones, yellow tones, and purple tones. The blue-toned colors account for a large proportion of the color chart and are more obviously distributed in the color chart, mainly in the SC-HC area. Yellow and purple tones are all in the SW-HW zone and a small part in the middle area. Therefore, the two zones, SW-HW and SC-HC, are the main color extraction zones. Three colors in the same color zone are extracted from SC-HC, two colors are extracted from SW-HW, and the remaining 1 group of colors are extracted from the two color zones, respectively. The color extraction process is shown in the figure below:

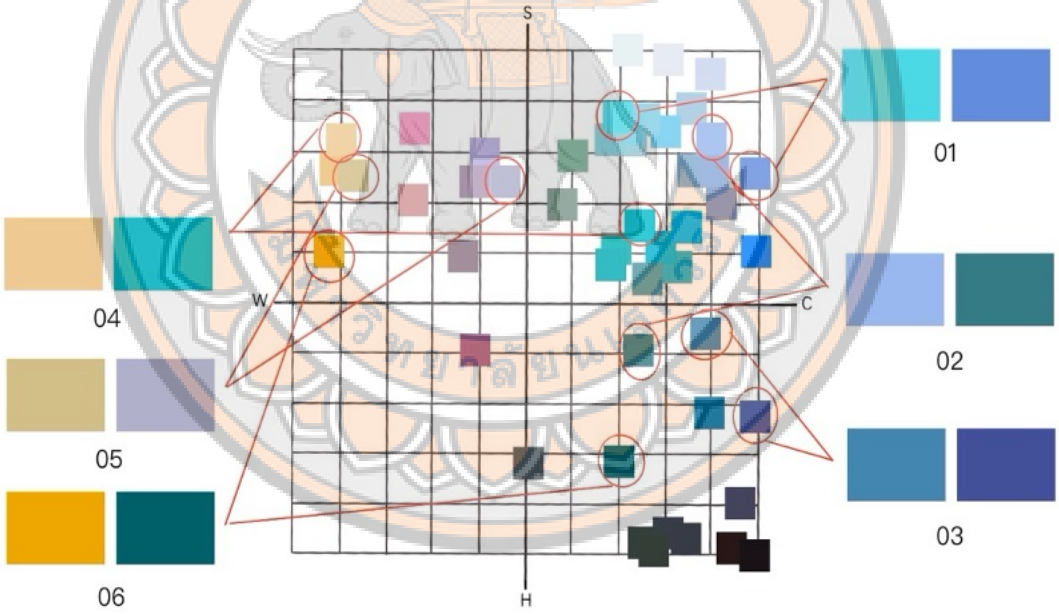


Figure 82 CA-8 Taking Color

From the two zones, six groups of colors were randomly taken out as follows:

Group 01: C8-P4 C8-Y9

Group 02: C8-Y7 C8-R10

Group 03: C8-Y3 C8-G8

Group 04: C8-B5 C8-R11

Group 05: C8-B4 C8-G6

Group 06: C8-B1 C8-R5

6 groups of colors were exchanged layered dyeing and transparency adjustments, and the results are shown in Figure CT-8:

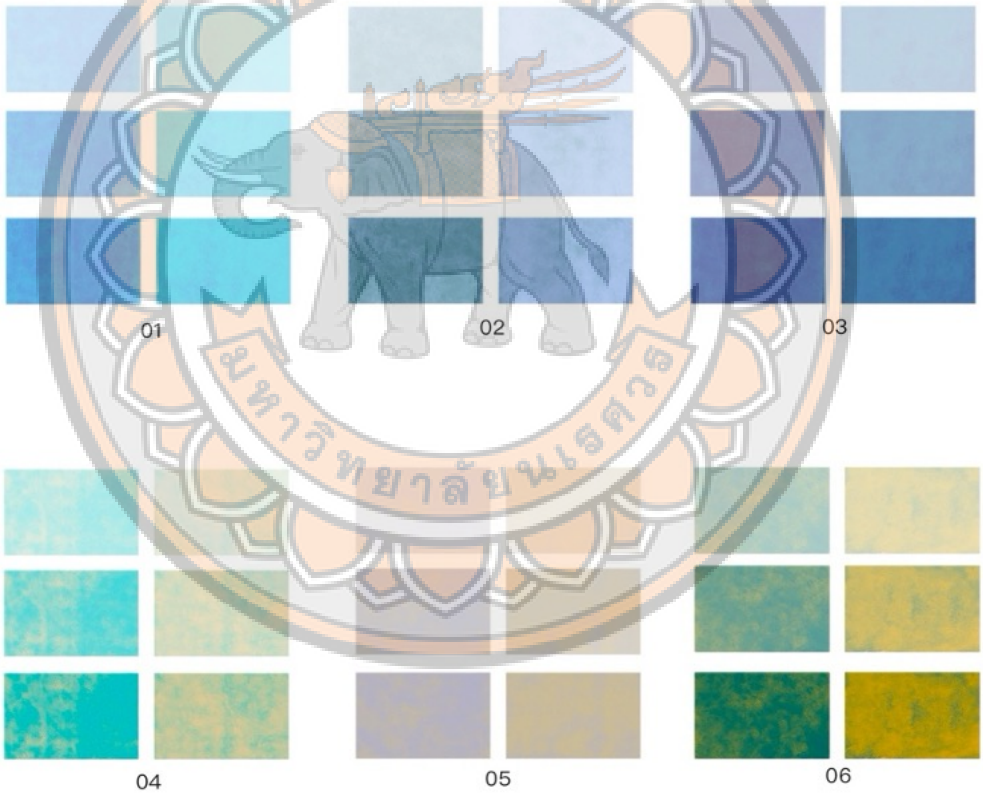


Figure 83 CT-8

4.5 Color Area Statistics

In this section, we will compare the original eight murals selected as samples to the supplemental color charts, create a 256-color swatch of each mural using the supplemental color charts, provide statistics on the percentage of the area of each color used through the card, and provide statistics on the distribution area of each color used.

4.5.1 Northern Liang Period: Cave 275 (West side of the north wall·Jātaka of the King Vilenjeli)

Figure 84 Sample 1 Location

Figure 85 Sample 1 Original

Figure 86 Sample 1 Restored

Figure 87 Sample 1 256 Color Chat

Table 22 Sample 1 Color Distribution and Area

Theme	Color	Proportion	Color Distributions				
			FB	BG	CH	LD	OL
Jātaka of the King Vilenjeli	R	42.58%		√	√	√	
	G	16.02%			√	√	
	B	1.56%			√		
	BL	3.51%					√
	WH	30.47%	√		√	√	
	Y	5.86%			√		

In the image analysis of Jātaka of the King Vilenjeli from the Northern Liang period:

The area of red color is 42.58%, mainly distributed in the background, clothing, and headlight.

The area of green is 16.02%, mainly distributed in clothing, headlights, and decoration.

Blue has 1.56% of the area and is mainly distributed in the area of headlights.

Blacks make up 3.51% of the total and are mainly used in the area of outlines.

White has an area of 30.47% and is mainly distributed in the areas of the figure's face and body, clothing, and decoration.

Yellow has an area of 5.86% and is mainly distributed in clothing.

4.5.2 Northern Wei Period: Cave 254 (North wall·Jātaka of The King Síbi)

Figure 88 Sample 2 Location

Figure 89 Sample 2 Original

Figure 90 Sample 2 Restored

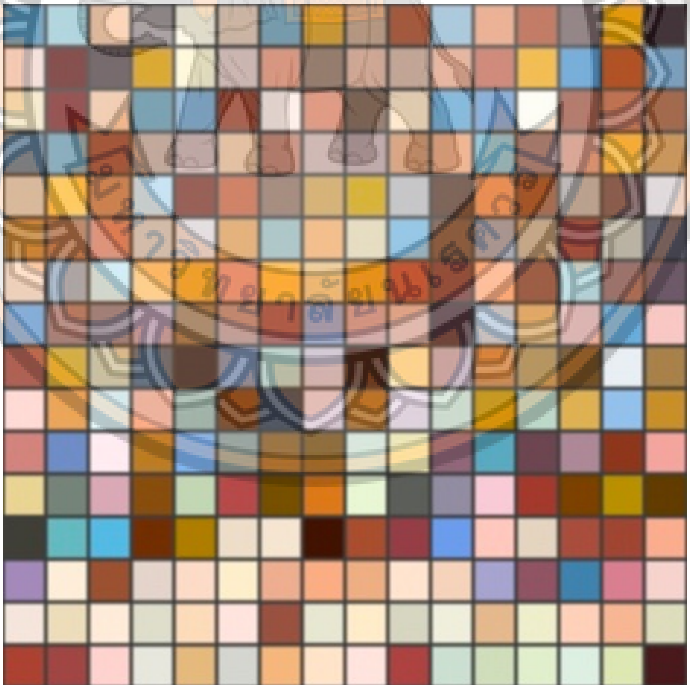


Figure 91 Sample 2 256 Color Chat

Table 23 Sample 2 Color Distribution and Area

Theme	Color	Proportion	Color Distributions				
			FB	BG	CH	LD	OL
Jātaka of The King Síbi	R	36.72%		√	√		√
	G	3.13%			√		
	B	12.89%			√	√	
	BL	3.13%	√		√	√	√
	WH	28.90%	√		√	√	
	Y	15.23%			√		

In the image analysis of Jātaka of King Síbi from the Northern Wei period:

The red color has 36.72% of the area and is mainly distributed in the background, clothing, headlights, and outlines.

The green color has 3.13% of the area, mainly in the headlight and clothing areas.

Blue covers 12.89% of the area, mainly in headlight, clothing, and decoration regions.

Black covers 3.13% of the area and is mainly distributed in the area of the figure's hair, clothing, landscape, and outline.

White represents 28.90% of the area and is mainly distributed in the figure's face, body, clothing, and landscape.

Yellow, 15.23% of the area, is mainly found in clothing.

No traces of the use of green were found.

4.5.3 Western Wei period: Cave 285 (South wall·Buddha Preaching of Sakya and Doppo paintings

Figure 92 Sample 3 Location

Figure 93 Sample 3 Original

Figure 94 Sample 3 Restored

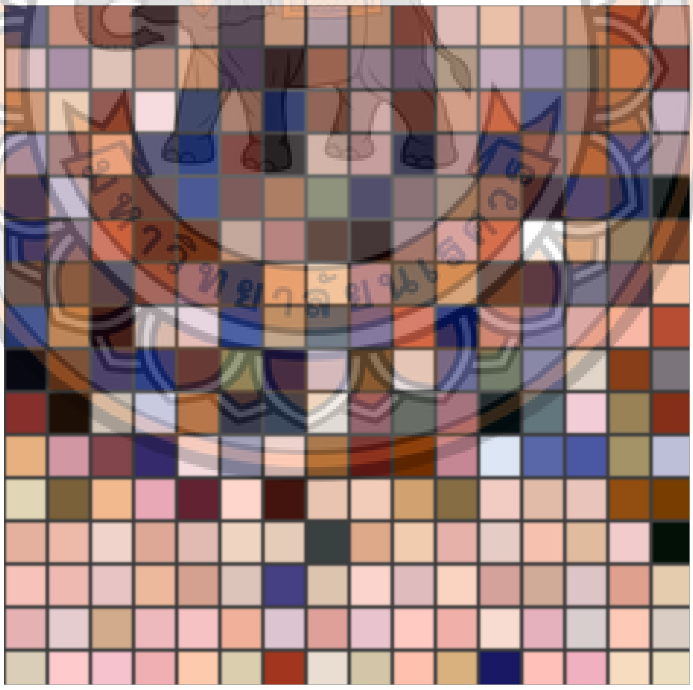


Figure 95 Sample 3 256 Color Chat

Table 24 Sample 3 Color Distribution and Area

Theme	Color	Proportion	Color Distributions				
			FB	BG	CH	LD	OL
Buddha Preaching of Sakya and Doppo paintings	R	28.52%			√	√	
	G	2.34%			√		
	B	14.45%	√		√	√	
	BL	4.69%	√		√	√	√
	WH	45.70%	√	√	√	√	
	Y	4.30%			√	√	

In the image analysis of Buddha Preaching of Sakya and Doppo paintings from the Western Wei period:

The area of red color is 28.52%, which is mainly distributed in clothing, headlights, and landscape.

Green color has 2.34% of the area and is mainly distributed in clothing and headlights.

Blue represents 2.34% of the area and is mainly distributed in the areas of the characters' hair, clothing, headlights, decorations, and landscapes.

The black color has 4.69% of the area and is mainly distributed in the area of the character's hair, clothing, decoration, landscape, and outline.

The white color has 37.89% of the area and is mainly distributed in the area of the figure's face and body, clothing, decoration, and landscape.

Yellow accounts for 3.91% of the area, mainly in clothing and decoration.

4.5.4 Northern Zhou Period: Cave 290 (Top·Buddha's life stories paintings·Partial）

Figure 96 Sample 4 Location

Figure 97 Sample 4 Original

Figure 98 Sample 4 Restored

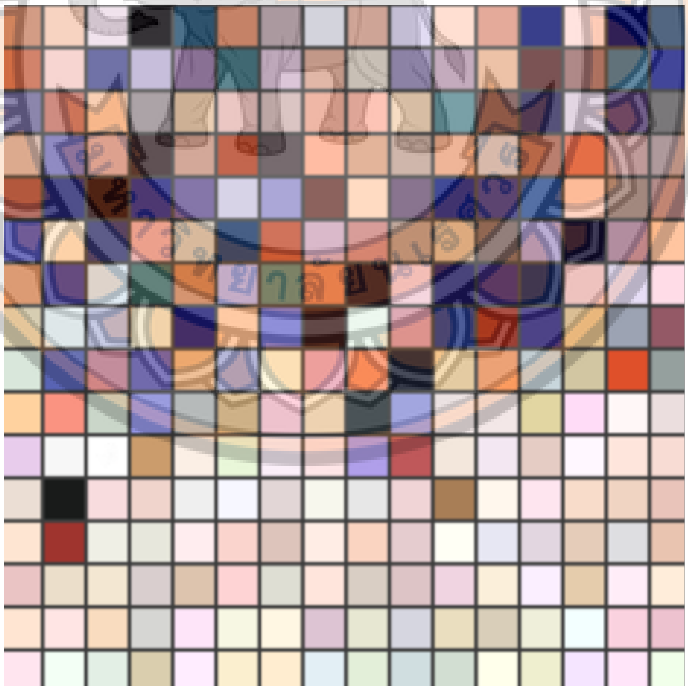


Figure 99 Sample 4 256 Color Chat

Table 25 Sample 4 Color Distribution and Area

Theme	Color	Proportion	Color Distributions				
			FB	BG	CH	LD	OL
Buddha's Life Stories paintings （Partial）	R	27.73%			√	√	√
	G	1.56%				√	
	B	17.58%				√	
	BL	3.91%			√	√	
	WH	49.22%	√	√			
	Y	-					

In the image analysis of Buddha Preaching of Sakya and Doppo paintings from the Northern Zhou period:

The red color covers 27.73% of the area and is mainly distributed in clothing, landscape, and outline.

Green color has 1.56% of the area and is mainly distributed in the landscape area.

Blue has 17.58% of the area, mainly distributed in landscape areas.

Blacks comprise 3.91% of the area, mainly in clothing and landscape.

White makes up 49.22% of the area, mainly in the areas of the figure's face, body, and background.

No traces of the use of yellow were found.

4.5.5 Early Tang period: Cave 57 (Left side of the south wall·Buddha Preaching paintings·Portrait of Avalokiteśvara）

Figure 100 Sample 5 Location

Figure 101 Sample 5 Original

Figure 102 Sample 5 Restored

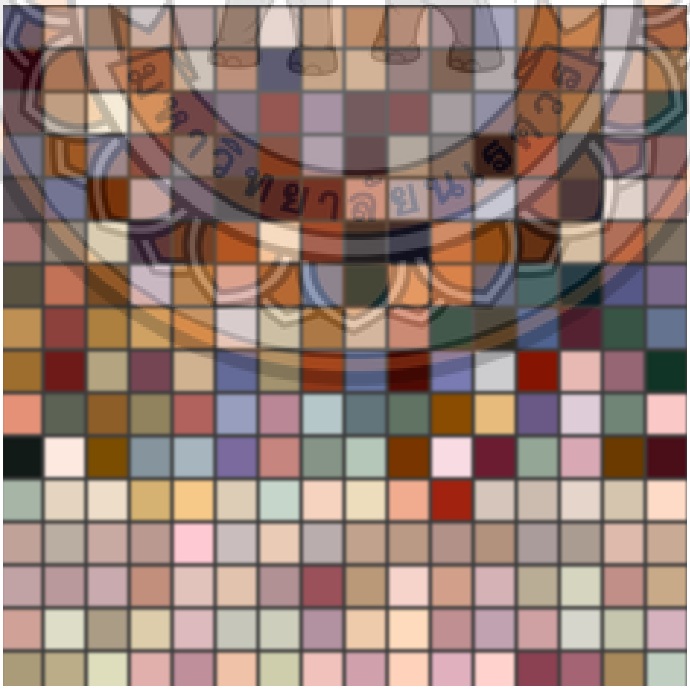


Figure 103 Sample 5 256 Color Chat

Table 26 Sample 5 Color Distribution and Area

Theme	Color	Proportion	Color Distributions				
			FB	BG	CH	LD	OL
Buddha Preaching paintings (Portrait of Avalokiteśvara）	R	20.31%			√		
	G	6.25%			√		
	B	10.55%			√	√	
	BL	5.47%			√	√	√
	WH	50.39%	√	√	√	√	
	Y	7.03%			√		

In the image analysis of Buddha Preaching paintings (Portrait of Avalokiteśvara) of the early Tang period:

The area of red color is 20.31%, which is mainly distributed in the area of clothing and headlights.

Green color has 6.25% of the area and is mainly distributed in the area of clothing.

Blue represents 10.55% of the area and is mainly distributed in clothing, headlights, and decoration.

Black has an area of 5.47% and is mainly distributed in clothing, decoration, and outline.

White has an area of 50.39% and is mainly distributed in the areas of the figure's face, body, clothing, decoration, and background.

Yellow has 7.03% of the area and is mainly distributed in clothing.

4.5.6 Flourishing Tang period: Cave 320 (Top of the south wall·Buddha Preaching of Sakya paintings (Picture of flying Apsaras)

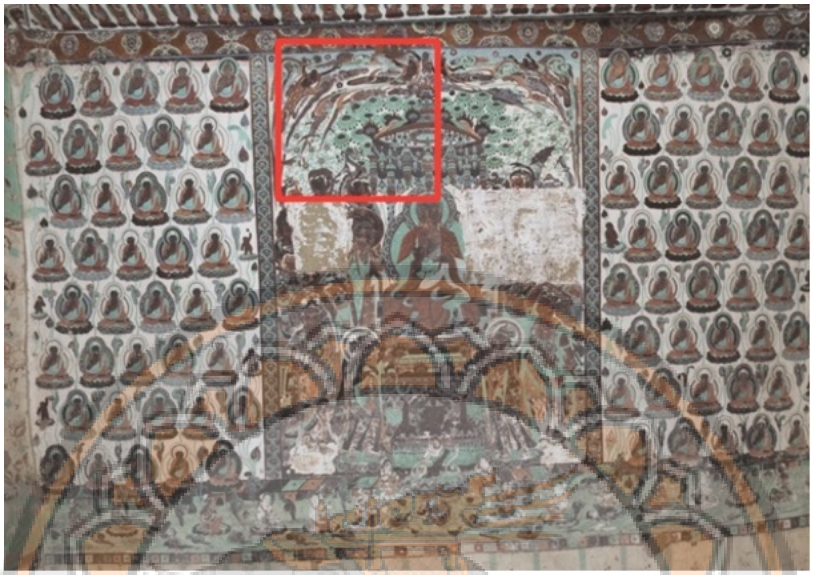


Figure 104 Sample 6 Location

Figure 105 Sample 6 Original

Figure 106 Sample 6 Restored

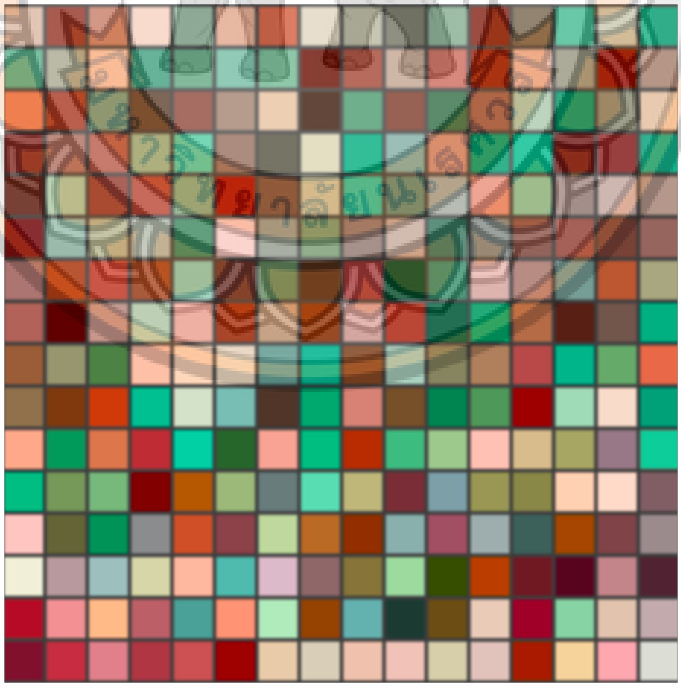


Figure 107 Sample 6 256 Color

Table 27 Sample 6 Color Distribution and Area

Theme	Color	Proportion	Color Distributions				
			FB	BG	CH	LD	OL
Buddha Preaching of Sakya paintings (Picture of flying Apsaras)	R	39.84%			√	√	
	G	32.03%			√	√	
	B	3.91%				√	
	BL	4.69%				√	√
	WH	19.53%	√	√	√	√	
	Y	-					

In the image analysis of Buddha Preaching of Sakya paintings (Picture of flying Apsaras) in the Flourishing Tang period:

The area of red color is 39.84%, which is mainly distributed in garments, decorations, and landscapes.

Green makes up 32.03% of the area and is mainly distributed in clothing, decoration, and landscape.

Blue has 3.91% of the area, mainly in decoration and landscape.

Blacks comprise 4.69% of the area and are mainly distributed in the areas of decoration and outline.

White represents 19.53% of the area and is mainly distributed in the figure's face, body, clothing, decoration, and background.

No traces of the use of yellow were found.

4.5.7 Middle Tang period: Cave 159 (South side of the east wall· The Sutra of Vimalakirti paintings·Picture of Tubo Zangpo performing a Buddhist rite)

Figure 108 Sample 7 Location

Figure 109 Sample 7 Original

Figure 110 Sample 7 Restored

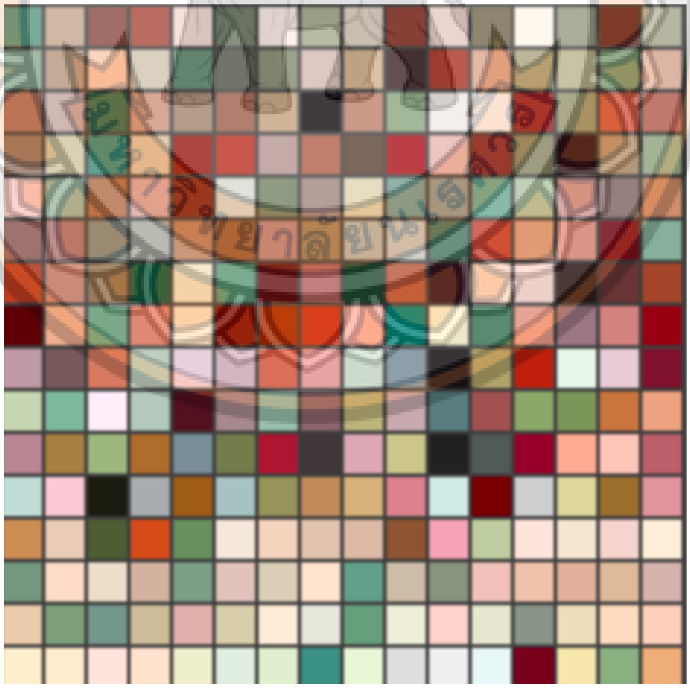


Figure 111 Sample 7 256 Color Chat

Table 28 Sample 7 Color Distribution and Area

Theme	Color	Proportion	Color Distributions				
			FB	BG	CH	LD	OL
The Sutra of Vimalakirti paintings (Picture of Tubo Zangpo performing a Buddhist rite)	R	22.26%			√	√	
	G	23.83%		√	√	√	
	B	3.13%				√	
	BL	4.69%			√	√	√
	WH	39.45%	√	√	√	√	
	Y	6.64%			√		

In the image analysis of The Sutra of Vimalakirti paintings (Picture of Tubo Zangpo performing a Buddhist rite) from the Middle Tang period:

The area of red is 22.26%, mainly in clothing, decoration, and landscape.

The area of green color is 23.83%, which is distributed primarily in the background, clothing, decoration, and landscape.

Blue has 3.13% of the area, mainly in decoration.

Blacks comprise 4.69% of the area and are distributed primarily in clothing, decoration, landscape, and outline.

White has 39.45% of the area and is mainly distributed in the areas of the figure's face, body, clothing, decoration, landscape, and background.

Yellow is used in 6.64% of the area and is mainly distributed in the clothing area.

4.5.8 Late Tang Dynasty: Cave 144 (North Wall·The Sutra of Gratitude paintings·Dancer)

Figure 112 Sample 8 Location

Figure 113 Sample 8 Original

Figure 114 Sample 8 Restored

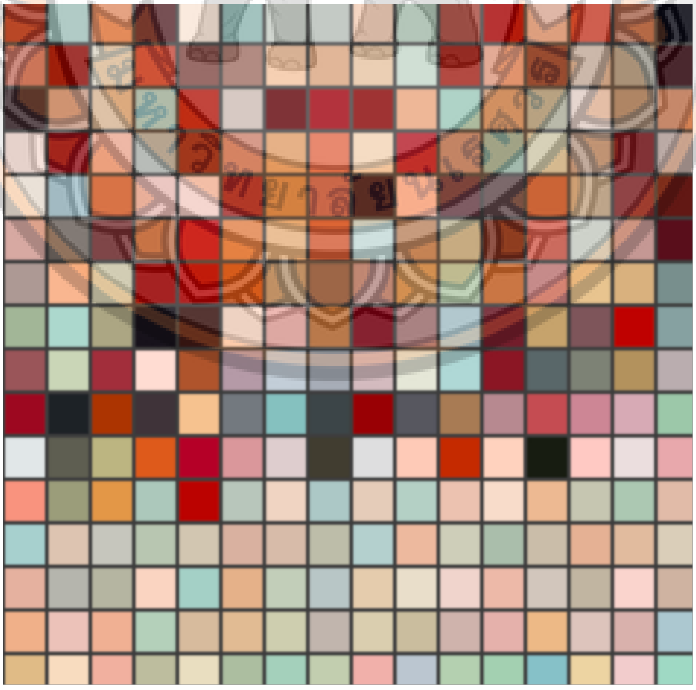


Figure 115 Sample 8 256 Color Chat

Table 29 Sample 8 Color Distribution and Area

Theme	Color	Proportion	Color Distributions				
			FB	BG	CH	LD	OL
The Sutra of Gratitude paintings (Dancer)	R	33.20%			√	√	√
	G	23.83%		√	√	√	
	B	-					
	BL	5.47%			√	√	
	WH	34.37%	√	√	√	√	
	Y	3.13%				√	

In the image analysis of Buddha Preaching of Sakya paintings (Picture of flying Apsaras) in the Sheng Tang period:

The red color covers 33.20% of the area and is mainly distributed in clothing, decoration, landscape, and outline.

Green covers 23.83% of the area, mainly in backgrounds, clothing, decoration, and landscape.

Blacks comprise 5.47% of the area, mainly in clothing, decoration, landscape, and outline.

White has 34.37% of the area, mainly distributed in the area of the figure's face, body, clothing, decoration, landscape, and background.

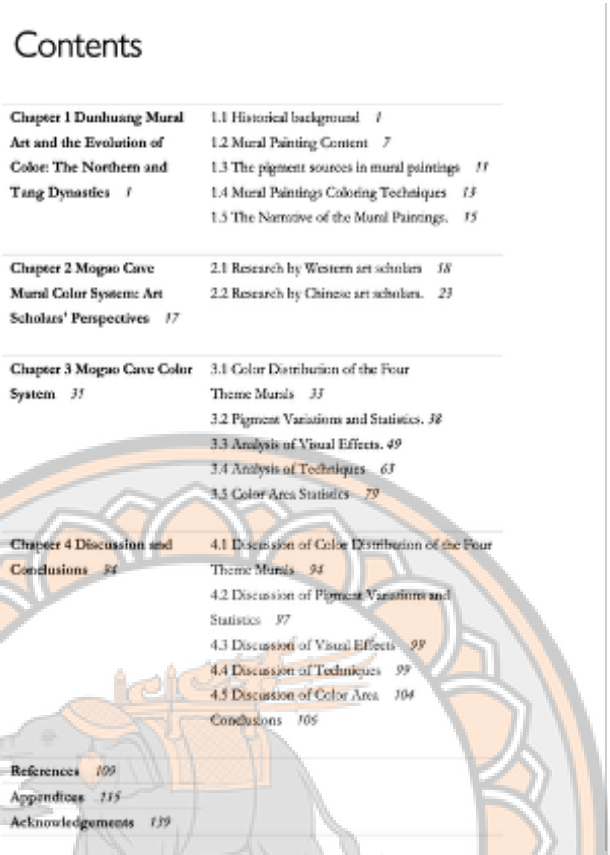
Yellow has 3.13% of the area and is mainly distributed in decoration and landscape.

No traces of the use of blue were found.

4.6 Formulation and Presentation of the Book

Each of the aspects required to formulate a color system for the Mogao Cave murals has been analyzed separately and in detail in the aforementioned sections 4.1 to 4.5. Based on this comprehensive analysis, this section presents the final outcome of this study: The Reorganization Of Color System Based On Mogao Cave Mural Paintings. This book is the concrete practical outcome of Research Objective 3, which aims to reorganize and formulate a Dunhuang mural painting color system that can be understood, referenced and applied.

The book consists of five main parts: introduction, color view from different perspectives, research methodology, Mogao cave color system, and discussion. This structure inherits the research framework of this thesis in terms of content, and extends and adjusts it in terms of expression, with the aim of weakening the language barriers of professional scholarship while retaining the depth of the research, so that readers from non-professional backgrounds can also clearly understand the core features and cultural significance of the colors of Dunhuang murals.



Contents

Figure 116 Presentation of book contents

The content of this book maintains a high degree of consistency with this thesis in terms of its overall structure and research line, which not only continues the systematic nature of the thesis in terms of research object, theoretical framework and analytical methodology, but also carries out appropriate transformation and reconstruction in terms of expression and presentation of content. This consistency has an important rationality: it ensures the academic rigor and credibility of this book in terms of theoretical basis and research conclusions. In this way, the book is both a condensed presentation of the research content of the thesis and a translation of knowledge for a wider audience.

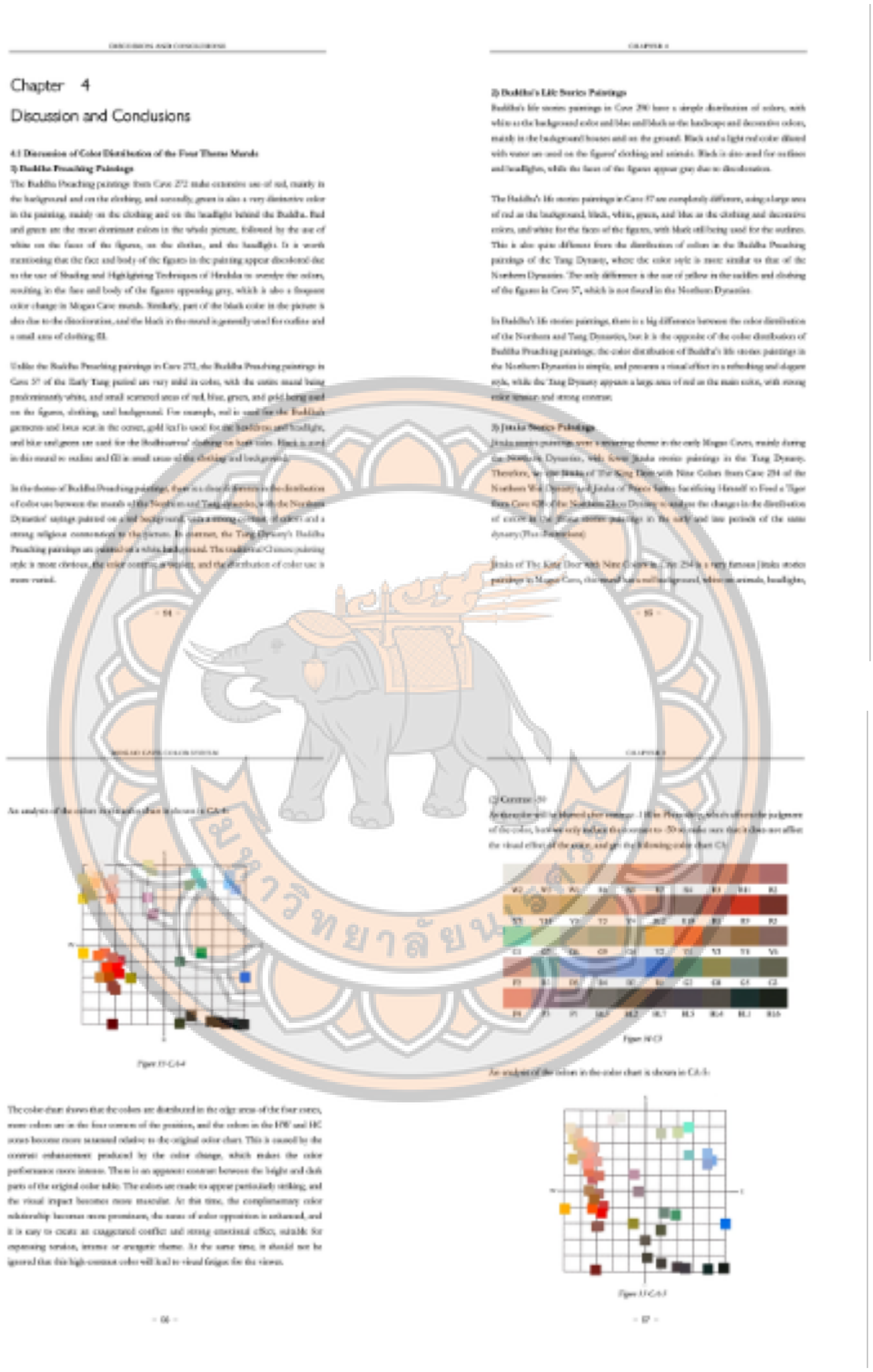


Figure 117 Book Inside Presentation

The front and back covers of this book use The Sutra Paintings of the Dharma Flower mural from the south wall of Cave 217 in the Flourishing Tang Dynasty as the main visual image, with color bar elements along the lower edge of the front cover and on the top of the back cover. Through the combination of color refinement and thematic images, the research content of the book is presented intuitively in the design of the front cover, which strengthens the readers' first impression and recognition.

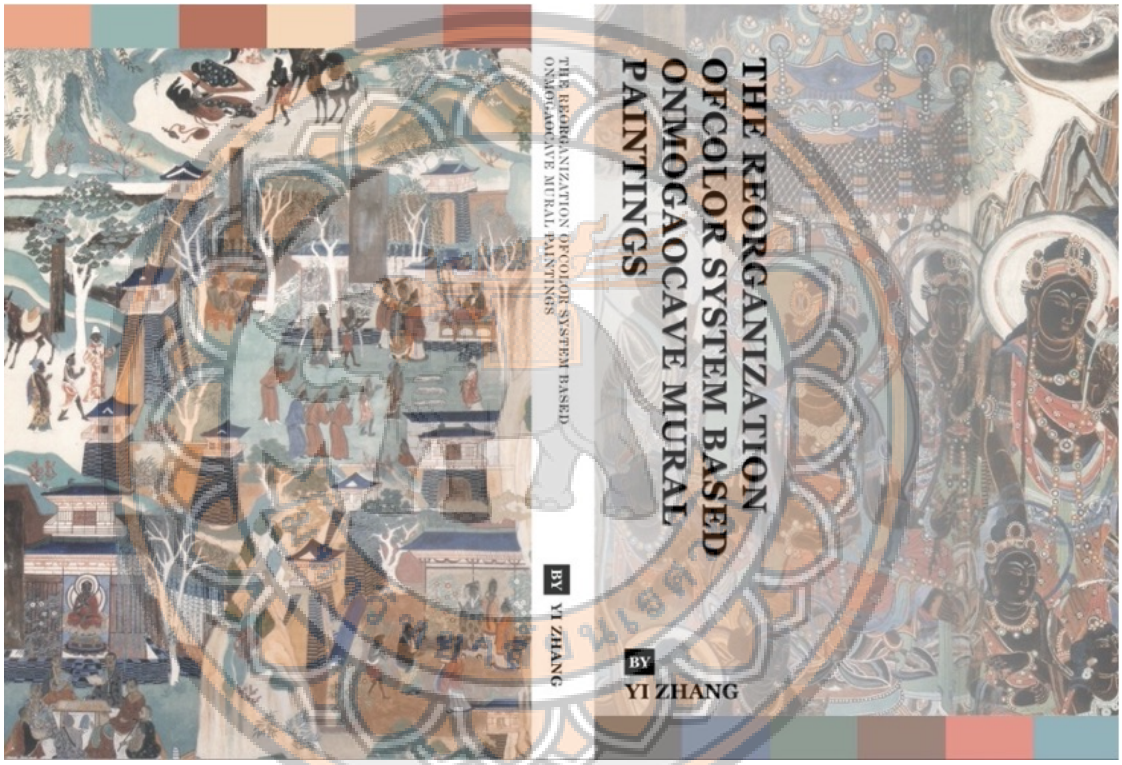


Figure 118 Cover Design Presentation

CHAPTER V

DISCUSSION AND CONCLUSIONS

5.1 Discussion of Color Distribution of the Four Theme Murals

5.1.1 Buddha Preaching Paintings

The Buddha Preaching paintings from Cave 272 make extensive use of red, mainly in the background and on the clothing, and secondly, green is also a very distinctive color in the painting, mainly on the clothing and on the headlight behind the Buddha. Red and green are the most dominant colors in the whole picture, followed by the use of white on the faces of the figures, on the clothes, and the headlight. It is worth mentioning that the face and body of the figures in the painting appear discolored due to the use of Shading and Highlighting Techniques of Hinduka to overdye the colors, resulting in the face and body of the figures appearing grey, which is also a frequent color change in Mogao Cave murals. Similarly, part of the black color in the picture is also due to the discoloration, and the black in the mural is generally used for outline and a small area of clothing fill.

Unlike the Buddha Preaching paintings in Cave 272, the Buddha Preaching paintings in Cave 57 of the Early Tang period are very mild in color, with the entire mural being predominantly white, and small scattered areas of red, blue, green, and gold being used on the figures, clothing, and background. For example, red is used for the Buddha's garments and lotus seat in the center, gold leaf is used for the headdress and headlight, and blue and green are used for the Bodhisattvas' clothing on both sides. Black is used in this mural to outline and fill in small areas of the clothing and background.

In the theme of Buddha Preaching paintings, there is a clear difference in the distribution of color use between the murals of the Northern and Tang dynasties, with the Northern Dynasties' sayings painted on a red background, with a strong contrast of colors and a strong religious connotation to the picture. In contrast, the Tang Dynasty's Buddha Preaching paintings are painted on a white background. The traditional Chinese painting style is more obvious, the color contrast is weaker, and the distribution of color use is more varied.

5.1.2 Buddha's Life Stories Paintings

Buddha's life stories paintings in Cave 290 have a simple distribution of colors, with white as the background color and blue and black as the landscape and decorative colors, mainly in the background houses and on the ground. Black and a light red color diluted with water are used on the figures' clothing and animals. Black is also used for outlines and headlights, while the faces of the figures appear gray due to discoloration.

The Buddha's life stories paintings in Cave 57 are completely different, using a large area of red as the background, black, white, green, and blue as the clothing and decorative colors, and white for the faces of the figures, with black still being used for the outlines. This is also quite different from the distribution of colors in the Buddha Preaching paintings of the Tang Dynasty, where the color style is more similar to that of the Northern Dynasties. The only difference is the use of yellow in the saddles and clothing of the figures in Cave 57, which is not found in the Northern Dynasties.

In Buddha's life stories paintings, there is a big difference between the color distribution of the Northern and Tang Dynasties, but it is the opposite of the color distribution of Buddha Preaching paintings; the color distribution of Buddha's life stories paintings in the Northern Dynasties is simple, and presents a visual effect in a refreshing and elegant style, while the Tang Dynasty appears a large area of red as the main color, with strong color tension and strong contrast.

5.1.3 Jātaka Stories Paintings

Jātaka stories paintings were a recurring theme in the early Mogao Caves, mainly during the Northern Dynasties, with fewer Jātaka stories paintings in the Tang Dynasty. Therefore, we cite Jātaka of The King Deer with Nine Colors from Cave 254 of the Northern Wei Dynasty and Jātaka of Prince Sattva Sacrificing Himself to Feed a Tiger from Cave 428 of the Northern Zhou Dynasty to analyze the changes in the distribution of colors in the Jātaka stories paintings in the early and late periods of the same dynasty.(Plus illustrations)

Jātaka of The King Deer with Nine Colors in Cave 254 is a very famous Jātaka stories paintings in Mogao Cave, this mural has a red background, white on animals, headlights, figure's body and clothing, green on clothing and landscape, and black on animals, landscapes, and outlines. The white of the faces and bodies of the figures in

this mural appear black and gray due to discoloration. The color distribution characteristics are quite similar to the Buddha Preaching paintings of the Northern Liang period.

The Jātaka of Prince Sattva Sacrificing Himself to Feed a Tiger in Cave 428 is similar to the Buddha's life stories paintings in Cave 290 in that it is in the form of a comic strip, and the distribution of colors is also in the form of white as the background color, with red being used to decorate the clothes and landscape, and blue being used to depict the landscape, and black being used to outline the landscape, clothes, animals, and lines. White is used as the background color, red to decorate the clothes and landscapes, blue to depict the landscapes, and black to depict the landscapes, clothes, animals, and outlines. Though the use of specific colors is different, the distribution of colors is similar to that of the Jātaka stories paintings in Cave 254.

Jātaka stories paintings from the Northern Wei and Northern Zhou periods are similar in their color distribution patterns. Although the use of specific colors is different, the presentation effect is also similar. The murals of the Northern Wei period are dominated by red, which has a strong color impact, while the murals of the Northern Zhou period are dominated by white, but the use of red and blue in the painting still has a strong contrast and color impact.

5.1.4 The Sutra paintings

The Sutra painting of Amitabha Buddha from Cave 321 is unique in its use of color. The blue color occupies the entire upper half of the painting, appearing as a background color, while the lower half of the painting is left with a large amount of white, with only green, red, and black used as accent colors for the figure's clothing and landscape, black is used as an outline, and the white of the figure's face continues to appear to be a discoloration. The painting is full of color tension. The complex use of color in The Sutra painting during the Tang Dynasty gradually emerged, and the programmatic nature of The Sutra painting during this period was not yet apparent, so the color presentation in the painting is very innovative.

The Sutra painting of Amitayus in Cave 172 shows the highest level of The Sutra painting in the Tang Dynasty. The distribution of colors is very much in line with the main features of Tang murals, i.e., white in the background, a lot of green in the figures'

clothing and landscapes, a reduction in the use of red and blue, which appear only in some landscapes and clothing, white and black in the headlights, black in the outlines, and the use of yellow in some of the clothing and landscaping areas.

In The Sutra painting, although the Early Tang and the Flourishing Tang periods are connected in time, there is still a great difference in the color style of the murals, The Sutra painting in the Early Tang period is bolder in the use of color, creating a very distinctive color experience, while The Sutra painting in the the Flourishing Tang period presents a very characteristic period color distribution, thereafter, the color distribution of The Sutra painting in the Middle Tang and Late Tang periods is gradually programmed, and the whole is similar to The Sutra painting of Amitayus.

In summary, the following conclusions can be drawn from the analysis of the color distribution of the above 8 murals of four different themes of the Northern Dynasties and the Tang Dynasty: first of all, the color distribution of each theme is different, and the reason for the difference is mainly due to the difference of the times and the needs of the painting. The mural paintings of the Northern Dynasty are relatively single and regular in the distribution of colors, while the Tang Dynasty murals have more scattered colors and more diverse ways of color distribution.

5.2 Discussion of Pigment Variations and Statistics

In the red, except for the three pigments of red coral, cinnabar soil, and soil red, all other pigments are relatively stable and suitable for creating works of art. Red coral, vermilion, and earth red can also be used under certain conditions. Referring to the murals of Mogao Caves in the Northern and Tang Dynasties, the red part of the murals using these pigments is easy to discolor.

Green pigments, such as grass green, Lijiu, yellow-green, and light green, are mineral pigments that are less stable and are recommended for creating works of art that do not need to be preserved for long periods. In contrast, the other pigments are more stable and can be used to make any work of art.

The blue pigments are stable except for blue-gray, resistant to light and heat under natural conditions, have high color rendering, and are very suitable for artistic creations.

From the composition analysis, the yellow pigment, Qiang cha, and Rock yellow soil appeared in the mural paintings of the Tang Dynasty. Androgynous and Orpiment

are not highly stable, so there is discoloration and fading in Mogao Cave murals. Tea color, Qiang cha, Brown, Gold tea powder, and Rock gold tea are more stable in the general environment. Rock-yellow soil is a mixture of substances; some components easily dissolve in an acidic environment, but the whole is more stable. Rock Jiaocha and Gold Yellow may change chemically under certain conditions, especially when exposed to acid or humidity. Pigments can be selected for artwork creation based on their different properties.

Although the purple color did not appear in the murals of the Mogao Caves in the Northern Dynasties and the Tang Dynasty because of the limitations of the period, it is undeniable that in this study, purple pigments are stable in nature and bright in color, which are perfect for use in the creation of works of art.

Black pigment, tourmaline powder, Obsidian powder, rock black, and graphite are all highly stable and adaptable to different environments, with graphite being the most heat—and corrosion-resistant. Brown black and Pyrolite black are relatively stable, and Purple black is less stable. Suitable pigments can be selected according to the nature of the pigment to be used in the creation of artworks.

Three white pigments are highly stable and ideal for creating works of art.

In this section, a total of 50 pigments in seven categories, including red (R1-R12), green (G1-G9), blue (B1-B5), yellow (Y1-Y10), violet (P1-P4), black (BL1-BL7), and white (W1-W3), have been collected, which include those used in the mural paintings of the Mogao Caves, as well as newly discovered mineral pigments, and the color cards presented for the 50 pigments in this section will be used as samples in the study of visual effects and techniques. These pigments are used to create works of art that achieve the effects and textures of the pigments used in the Mogao cave murals.

5.3 Discussion of Visual Effects

Through the analysis of the eight color charts, the following conclusions are drawn: firstly, no matter how the color brightness, contrast, and hue are changed, the colors show the form of complementary colors, so the use of Mogao Cave mural colors, no matter how the colors are changed, is still based on the complementary relationship, with high sharpness complementary colors (such as C2 and C4 color charts) and low sharpness complementary colors (such as C3 color charts) as the distinction. This

distinction makes the colors of the Mogao Cave murals visually show a very high degree of sharpness and impact.

Secondly, no matter how the colors change, the colors in the black family (BL) change less, which indicates the use of Mogao Cave mural colors, which generally present a high contrast effect. Black is indispensable in the colors of Mogao cave murals, and its stability and consistency make the picture maintain a sense of visual balance and contrast even as the colors change. This feature makes the BL color in the color table, regardless of brightness and contrast, such as the hue how to change, always maintain its original color characteristics and further enhance the integrity of the picture and visual impact.

Finally, by analyzing each color chart's characteristics and common points, we can see that the Mogao Cave mural painting colors have a distinctive recognizability. Although the colors have changed under different conditions, their color relationships have not significantly fluctuated, which indicates that these colors have strong cultural and artistic characteristics and can maintain their distinctive visual effects and styles in different environments. If more recognition is needed, combining the study of color techniques is necessary. The specific content will be analyzed in 4.4. Provide more comprehensive theoretical support for understanding and using the color of Mogao Cave murals.

Through comparative analysis of eight sets of color distribution maps, this study reveals that colors exhibit highly consistent and directional structural patterns within the two-dimensional CMYK mapping space. Overall, colors with high C values are stably distributed in the upper or upper-left regions of the image. As M and Y values increase, colors gradually shift toward the right and lower-right areas, forming a continuous gradient transitioning from cool to warm tones. Simultaneously, when the ratios of C, M, and Y become closer and the K value increases, colors noticeably converge toward the image center, manifesting as a band of low-saturation neutral colors. This phenomenon indicates that the K channel plays a role in reducing differences and enhancing concentration within the overall color coordinate system.

All eight image sets exhibit the aforementioned distribution structure, demonstrating the cross-sample consistency and stability of this color model. Regardless of color origin, luminance variation, or saturation changes, the proportional

relationships between CMYK values consistently form identical spatial organizational structures within the two-dimensional coordinate system. Consequently, the proposed color mapping method not only effectively reveals the behavioral mechanisms of CMYK values within the color space but also provides a reliable analytical framework for subsequent investigations into the structural characteristics and evolutionary pathways of the Dunhuang mural color system.

5.4 Discussion of Techniques

Through the demonstration of CT-1, it can be found that the layers become rich after layered dyeing. The layered dyeing of cool and warm colors will change the color tendency into neutral colors with a balanced contrast between warm and cool, producing delicate color clashes and fusion, bringing visual impact, as shown in the 06 group of colors. The layered dyeing of colors with high saturation and low saturation will make certain parts of the colors more vivid and enhance the visual focus, as shown in the colors of groups 02, 04, and 05. The colors of groups 01 and 03 are the layered dyeing of colors in different color zones but with similar chromaticity, which presents intermediate color characteristics with high vividness. In addition, the change of transparency makes the colors present different layers of color levels. It can be found that the colors offered by different transparency have changes in brightness, contrast, saturation, etc., and the sense of layers is more distinct. Using colors with different color levels for creation also helps to enhance the understanding of space. Although the colors have changed to different degrees, the whole still presents the characteristics of high contrast between the complementary colors. These simulated layered dyeing color rendering effects usually also bring different visual impacts, which is distinctive of the Mogao Cave murals' color characteristics.

When extracting the colors from the CA-2 color analysis chart, choose as many colors as possible in the same color zone and adjacent color zones for layered dyeing, and it is easier to see the effect of layered dyeing of similar colors. Through the presentation of CT-2, it can be found that the color vividness becomes higher when high-brightness colors are layered dyeing. For example, the sharpness is increased in the 02 group of colors after layered dyeing. While 01, 04, 03, and 05 group colors are similar layered dyeing, 01 and 04 group colors belong to high brightness similar colors

layered dyeing, color translucency enhancement, saturation decreases, with a soft sense of light and a very delicate layer, with a visual sense of lightness and atmosphere. The 03 and 05 colors belong to the high-contrast, similar colors of layered dyeing. This layered dyeing enhances the depth of color and sense of hierarchy. However, the bottom color and the upper layer of the color contrast are intense but very harmonious and can naturally form a visual focus. Groups 02 and 06 are layered dyeing between complementary colors and saturation levels. The color of the sense of opposites is prominent and has a very rich color hierarchy. In conclusion, the layered dyeing of high-brightness colors presents a bright, light, and rich texture suitable for expressing some painting scenes with sufficient light and delicate emotions.

The presentation of CT-3 shows that the low-lightness colors present an overall thick and deep texture when layered dyeing. In the layered dyeing of low-brightness complementary colors, the sense of layers of colors is undeniable, but because of the low brightness, it presents a strong sense of depth and space. The underlying colors in the surface colors indicate color opposition and thickness enhancement. The hedging of cold and warm tones makes the color presentation very tense, for example, the colors of group 01 and group 05. Layered dyeing of low-brightness colors of the same hue does not have a strong sense of color opposition. The color harmony is deep but still has a delicate sense of layer, such as in group 02 and group 04 colors. While in the 03 and 06 groups of color layered dyeing it is the low brightness colors between high and low saturation, low brightness high saturation, and low brightness low saturation color layered dyeing so that the purity of the color has been adjusted to reduce the impact of the color, showing the effect of gray tones. The transparency adjustment makes the colors softer after reducing transparency, and the effect of layered dyeing is more integrated. In summary, low-bright color layered dyeing has the characteristics of deep, mysterious, depressing, and calm, and it is suitable for expressing complex emotions, has a heavy texture, and has a rich sense of space.

Through the demonstration of CT-4, it can be found that high-contrast colors show a strong color impact when layered dyeing and the color conflict between the bottom and upper colors are very strong. The six groups of colors chosen this time have relatively significant differences. 01, 02, 04, and 05 groups of colors belong to the same kind of colors. Still, the brightness and saturation of the colors have differences, so the

layered dyeing colors are bright and vivid and still have a strong visual impact, with a high degree of color saturation. The sense of layers is vibrant. 03 and 06 groups of colors belong to different color families, but the vast differences in the colors make the layered dyeing color produce a sense of disharmony, full of dramatic tension. High-contrast color layered dyeing of the overall sense of disharmony so that the colors show a sense of mottled; although the transparency of the change will make the color of the mottling sense of weakening, it will still make the color produce a dynamic visual effect as well as a rich sense of space and distance. In summary, high-contrast colors in layered dyeing have a strong visual impact, a clear sense of layer, and the reinforcement of emotion and atmosphere. It is suitable for expressing artworks with dynamism, drama, or strong emotions.

The demonstration of CT-5 shows that low-contrast colors show a gentle and calm sense of color atmosphere when layered dyeing. Due to the low contrast between the colors, there is no obvious demarcation line or intense conflict between the colors, and the layered dyeing looks smoother and more even, for example, the 01, 02, 04, 05, and 06 groups. This is the opposite of the effect of layered dyeing of high-contrast colors, where the sense of mottledness is significantly reduced. The change in transparency leads to a higher degree of color fusion, which maintains the overall unity of the hues and the sense of Harmony. To avoid intense color conflict, this mild color visual effect usually weakens the sense of three-dimensionality and spatial sense. 03 group color in the HC area, the color shows the sense of difference is the largest in the table of the color, which shows that in the low-contrast colors in the low brightness and high saturation, layered dyeing out of the effect is likely to produce a more intense visual effect. However, the overall colors still show a gentle, calm, and delicate visual effect. This effect is ideal for creating a subtle atmosphere. Since the contrast between the colors is not so strong, the image appears calmer and is often used to express scenes with gentle emotions and a serene atmosphere.

Through the demonstration of CT-6, it can be found that when the hue is changed, the color tendency is also altered, directly affecting the degree of color contrast in the layered dyeing process. Different hue colors have different visual contrasts; the more significant the difference in hue, the stronger the contrasting effect of layered dyeing. For example, in the 04 and 06 groups of colors, the layer of colors is pronounced, and

the overlaying dyeing between the highly saturated complementary colors creates a great sense of space; the smaller the difference in hue, the effect of overlaying dyeing is more muted and balanced, for example, the 01, 02, 03, and 05 groups of colors, the color fusion is high. Mottled sense is significantly less than the other two groups of colors, and this color overlay will produce a new hue, expanding the expressive power of the original color. After the hue change, the color change is reduced, but the sharpness is enhanced, showing a high degree of saturation visual effect. Therefore, the overall color presents a sharp contrast, which can create a strong visual impact and enrich the layers of the picture through layered dyeing of the same color. It is suitable for expressing modernity, technology, and art creations that must express complex emotions and changes in light and shadow.

Through the display of CT-7, it can be found that the color performance is similar to that of CT-6, and the hue changes the color tendency. Still, there are some differences in color performance with CT-6; the integration of layered dyeing between similar colors is reduced, and the 04, 05, and 06 groups of colors all belong to the same color area colors. Still, the effect of layered dyeing is different from that of layered dyeing with the same color in CT-6, and there is an undeniable sense of mottling. The change of transparency still has not weakened the contrast between the base color and the upper color, and the spatial sense of the color is powerful, which is different from the effect of layered dyeing with the same color in CT-6. The layered dyeing between complementary colors still has a strong sense of contrast and layer, such as the color effect of group 01 and group 03. Although group 02 belongs to the intermediate color layered dyeing, the effect is similar to that of the other two groups of colors, and the sense of conflict between the colors is increased, which has a strong visual impact. The colors in the color table show a heavy texture but with high saturation and sharpness of the visual effect. This dramatic conflict and contrast of colors is suitable for use in some expressions of conflict, danger, and complex emotional scenarios.

The CT-8 presentation shows that the hue changes the color tendency, and the integration of layered dyeing between similar colors and intermediate colors is relatively high. For example, the layered dyeing of the colors of group 01, group 02, group 03, and group 05 presents a soft and harmonious visual effect. At the same time, it will bring about a rich sense of layers. After the change of transparency, the fusion of the bottom

and upper colors deepens, the contrast decreases, and the overall gray tone and color are softer. The 04 and 06 colors belong to the complementary color layered dyeing, and the yellow and blue tones belong to the cold and warm opposing colors. The two layers of dyeing will form a bright sense of contrast, which expresses the vitality of the color and maintains the balance between the cold and warm, still having a strong sense of space. This group of colors as a whole presents a relatively harmonious color performance, which is relatively rare in the layered dyeing of complementary colors, which is related to the blue and yellow tones of colors layered dyeing to produce inter-colors so that the color to achieve a certain balance is related. The combination of the blue tone's calmness and the yellow tone's warmth makes the color harmonious and visually impactful after layered dyeing, which is suitable for expressing light and shadow, space, natural landscape, or emotional expression in various artistic creations.

In summary, this section has further clarified the uniqueness of the colors of the Mogao Cave murals through the analysis of the Shading and Highlighting Techniques of Hinduka. First, the effect of this technique is essential in making the colors of Mogao Grottoes frescoes distinctive. Therefore, the impact of using original color layered dyeing can be seen in CT-1. This layered dyeing effect is consistent with that of the colors of the existing Mogao Cave murals, which reveals a rich sense of layer and delicate changes between colors, and newly discovered mineral substances that are currently circulating on the market are added to the original colors so that the color performance is richer.

Secondly, this technique brings the most apparent quality of color, enhancing color layers and spatial sense. It is accompanied by a sense of heaviness, which further strengthens the characteristics of the color of the Mogao Grottoes murals. When the brightness, contrast, and hue are changed, the colors in the original color chart C1 also change, and this change is different; for example, the colors in CT-2 are bright and light, while the colors in CT-3 are calm and depressing. Color changes bring different layered dyeing effects, for example, also belonging to similar color layered dyeing, CT-4 and CT-7 in the warm color system of similar color layered dyeing, and CT-5, CT-6 in the cold color system of similar color layered dyeing rendering effect is not the same, which is mainly due to the relationship between the color of warm and cold. Therefore, the changes in color brightness, contrast, and hue bring about different layered dyeing

effects, which not only enrich the variety of colors in Mogao Cave murals but also add more paths for the use of the Mogao Cave mural color system on different occasions.

Finally, Shading and Highlighting Techniques of Hinduka is a crucial part of using the color system of Mogao Cave murals. Whether using pigments for painting or designing on electronic devices, it is an important symbol that can indicate the color characteristics of Mogao Cave murals. No matter what colors the creators use, all of them will have the color style of the Mogao Cave murals.

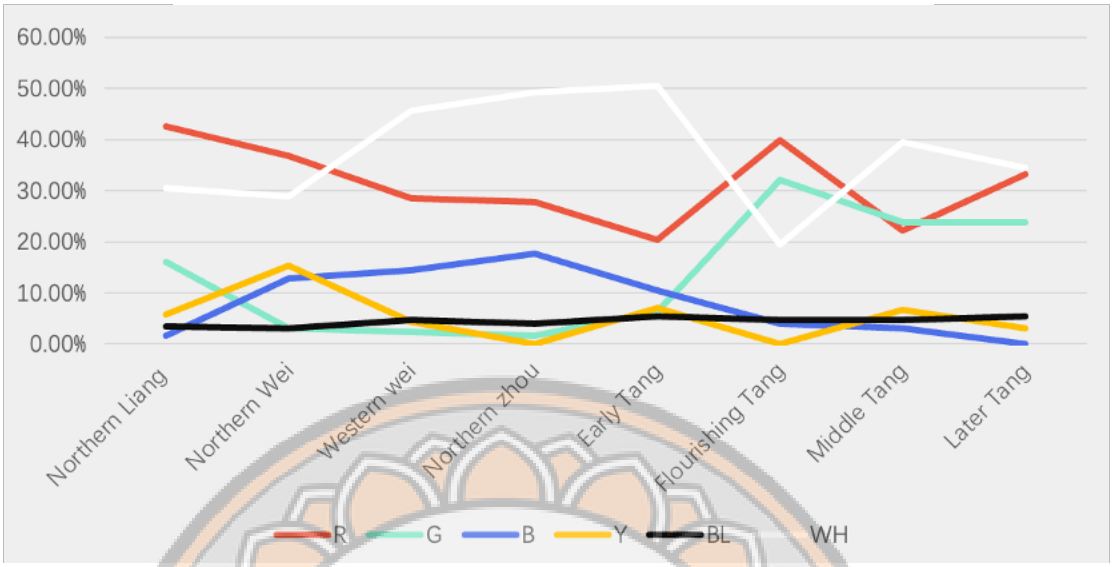
5.5 Discussion of Color Area

Color use rates and variations are summarized below:

Table 30 Color Use Rates and Variations

Period	Red	Green	Blue	Yellow	Black	White
Northern Liang	42.58%	16.02%	1.56%	5.86%	3.51%	30.47%
Northern Wei	36.72%	3.13%	12.89%	15.23%	3.13%	28.90%
Western Wei	28.52%	2.34%	14.45%	4.30%	4.69%	45.70%
Northern Zhou	27.73%	1.56%	17.58%		3.91%	49.22%
Early Tang	20.31%	6.25%	10.55%	7.03%	5.47%	50.39%
Flourishing Tang	39.84%	32.03%	3.91%		4.69%	19.53%
Middle Tang	22.26%	23.83%	3.13%	6.64%	4.69%	39.45%
Late Tang	33.20%	23.83%		3.13%	5.47%	34.37%

Table 31 Rate Changes of Colors in Different Periods



The above analysis shows that the color rate and distribution of Mogao Cave murals changed according to the different periods. White and red have the highest frequency and the widest range and are the most commonly used colors in Mogao Cave murals. At the same time, green began to increase during the Tang Dynasty, and blue was the opposite, with a relatively high frequency of use during the Northern Dynasty period and a gradual decrease in the Tang Dynasty. Black and yellow, although low in area of use, is essential and also belongs to the standard colors of Mogao Cave murals.

The color Area and usage rate of Mogao Cave murals can be used as a reference for artists creating artwork. Eight samples have been selected in this section, and all other murals can be counted and analyzed in terms of area and rate for use in creating artwork.

5.6 Discussion of the Book

As a practical result of this research, the color system is finally presented in the form of a book, which has the dual functions of “instrumental” and “educational”. In terms of tools, the book provides practical data such as pigment information, color cards, area distribution values, technique application effects, etc., providing art designers with color resources that can be directly applied. Educationally, the book presents the composition and significance of Dunhuang's color system in a graphic and logical way,

along with relevant sample analyses, making it easy for art students to conduct systematic learning and color matching training. The book not only conveys the results of academic research to readers in a more intuitive way, but also promotes the practical dissemination and reuse of Dunhuang color culture in teaching and design.

The target audience of this book consists of three main groups: art practitioners, art students, and interdisciplinary researchers. For art practitioners, such as painters, graphic designers, digital art creators, or developers of cultural and creative products, this book provides a new color system that can be used as an important reference for visual development. For art students, it can be used as a supplementary textbook for learning Dunhuang art and color theory, helping them to master color analysis methods and matching skills while understanding traditional culture. In addition, researchers in interdisciplinary fields such as cultural heritage preservation, religious studies, and material science can also make use of the methodological framework and analytical ideas of this book to expand their research and cultural reproduction attempts. Therefore, this book is not only a form of expression of research results, but also a medium of cross-border communication.

Conclusions

Through the in-depth analysis of Mogao Cave mural painting colors in multiple dimensions, this study aims to establish a more structurally complete color system. To achieve the above goals, this paper summarizes the basic information, color cards, chemical formulae and stability assessment of 50 mineral pigments, successively adopts color extraction and area statistics, visual analysis method to analyze the area, visual effects and techniques of the colors of the mural images, and combines them with symbolic meaning interpretation; finally, the research results are transformed into a visualized book.

This study presents several innovations in the development of color systems. First, in the study of color area, the thesis for the first time on the Mogao Caves in different periods, the use of color in murals of different subjects quantitative analysis, through accurate measurement of the proportion of each color, revealing the evolution of color tendencies in various periods of the evolution of the function of the color and narrative,

for the long-term lack of quantitative basis for the Dunhuang science of the color research to fill in the gaps.

Secondly, in the analysis of visual effects, the study uses the production of color tendency distribution table to visually display the different visual expression of Mogao Cave murals under different conditions of brightness, contrast and hue, discusses the commonalities and differences of murals' colors in various environments, and demonstrates the impact of other visual effects on the sense of space and hierarchy of the picture. This method breaks through the descriptive limitations of traditional image analysis and enhances the precision of Dunhuang color research and the depth of artistic interpretation.

Furthermore, by simulating the effect of the technique, the thesis reveals the key role of Shading and Highlighting Techniques of Hinduka in creating visual tension and emotional atmosphere through the simulation of the color overlay mechanism in the mural paintings. Based on the analysis of the visual effect, the simulation demonstrates the different overdyeing effects of different transparency by changing the transparency of each group of colors, which provides a new path of operation for the reconstruction of the color of the Mogao Cave murals and the contemporary visual re-creation.

In summary, this thesis establishes a new paradigm for the study of color in Dunhuang murals at multiple levels, breaking through the previous pattern of research that relied only on descriptions and image impressions of Dunhuang color, and forming a set of scientific, systematic, and applied color systems, laying the foundation for the contemporary expression and cross-disciplinary dissemination of Dunhuang art.

However, although this study is holistic and comparable, it also reveals several limitations. First, the color extraction of the murals in this study relies heavily on the existing visible images, ignoring the color deviations caused by weathering, mutilation, or modern restoration, resulting in some data that may not reflect the original color gamut of the murals. Second, the selected samples cover only typical caves of the Northern Dynasties and the Tang Dynasty, and do not include the diverse color practices of caves of the Western Xia, Song, Yuan, and later periods, which makes it difficult for the resulting system to be truly representative of the whole picture in terms of historical continuity and geographic diversity. Furthermore, although this book provides a wealth of color tools and teaching models for design practice, it still relies more on traditional

Buddhist symbols in its cultural semantic interpretation, and lacks a critical examination of the changes in folk beliefs, circuitous circulation and trade, and cross-cultural influences. Finally, the translation of academic research results into books improves readability, but may create a tension between depth and accuracy, making it difficult to balance professional research and mass communication. In the future, researchers should combine chemical composition micro-mapping, optical simulation of cave environments, and field surveys to expand the scope of samples and deepen the semiotic and socio-historical perspectives, in order to build a dynamic model of Dunhuang color that is both authentic and inclusive while respecting its historical originality.

The color system for Mogao Grottoes murals developed in this study comprises five components: color distribution patterns, pigment statistics, visual effect analysis, technique analysis, and color coverage area. It provides a methodologically significant reference framework for creative and research endeavors across diverse fields. For the field of artistic creation, this system helps creators systematically understand the color logic and visual strategies of Mogao Grottoes murals, enabling them to integrate historically rooted color relationships into contemporary painting, installation art, or digital art. For design-related fields—including visual communication design, product design, fashion design, and interior design—the system serves as a color planning tool. Designers can leverage its color distribution patterns and proportional structures to construct harmonious color schemes, enhancing cultural expressiveness and developing a Dunhuang-inspired design language. In cultural heritage conservation and digital restoration, the system's data on pigments, techniques, and visual effects provides scientific foundations for color restoration, virtual reconstruction, and immersive display technologies. Furthermore, in education and cultural dissemination, this system can serve as a pedagogical model, helping learners understand Dunhuang colors from multidimensional perspectives encompassing science, aesthetics, and technology. Through its analytical and applied structure, this color system demonstrates broad interdisciplinary application potential.

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APPENDIX

APPENDIX A EXPERT INTERVIEWS

Expert 1

Nationality: Chinese

Position: Associate Professor

Specialties: Dunhuang Studies, Chinese Painting

Q1: In developing Mogao Caves mural paintings, what are the characteristics of this stage from the Northern Dynasties to the Tang Dynasty? What is the place of this stage in history?

A: If we regard the Tang Dynasty, especially the period since the flourishing Tang, as the most mature Mogao Caves mural painting and more Han nationalization of the brilliant results, then the Tang Dynasty mural paintings of this content of the completeness of the form of perfection, the completeness of the technique, it requires a very deep preparation and accumulation to achieve. The period from the Northern Dynasties to the Tang Dynasty was a stage of conscious or unconscious exploration, pioneering, development, and integration. This period is the Dunhuang area, and various regime changes, ethnic integration, and religious exchanges are extremely frequent stages, so the appearance of a wide range of painting methods in the mural style is rare in other periods. Also, due to the different influences exerted by various regimes and religions on Dunhuang, the style of Dunhuang mural paintings at this stage has produced a sense of instability, sometimes rugged, sometimes sophisticated, sometimes foreignized, sometimes sinicized. The overall style of mural paintings in this period is more rustic, rugged, strong, simple, and varied than after the Tang Dynasty. It is precisely because of this diversity and instability that we can more easily explore the development of art in this historical period and make up for the deficiencies in the documentary records and the information about Chinese paintings that have been handed down to us. Therefore, the importance of this stage is irreplaceable, especially in the study of the evidence and materials that remain in the process of ethnic, religious, cultural, and artistic changes. As stated at the beginning, the mural paintings after the flourishing Tang were too mature and stable, and the degree of Sinicization was too high. In contrast, the materials of the mainstream Han Chinese painting history mainly were

deficient, so the value of the Mogao Grottoes mural paintings in this period also came to the fore.

Q2: Among the mural paintings from the Northern Dynasties to the Tang Dynasty, what mural contents are the most representative?

A: If I were to give examples based on my impression, I would choose three caves as the most representative mural paintings of this period. Because my focus on this period is more on the evolution of the mural paintings, they are not necessarily the most famous, but they are typical enough to show the different historical evolutions. One is the Northern Wei period, with the "Jātaka of Prince Sattva Sacrificing Himself to Feed a Tiger " on the south wall of Cave 254; the second is Cave 428, from the Northern Zhou period, After a tendency towards gradual refinement, the murals of this cave show a certain rusticity and clumsiness characteristic of an earlier period; and the third is Cave 420, from the Sui dynasty, which has a tendency toward flamboyance and precision that can be seen as reaching the Tang dynasty's peak. The third is Cave 420, from the Sui dynasty, with its flamboyance and sophistication, which can be seen as a bridge to the Tang dynasty. Of course, it is possible to choose different masterpieces from different perspectives.

Q3: In the content of these representative mural paintings, what do you think is the role of color in them? How is the importance of color reflected?

A: In these mural paintings, the color is firstly directly related to the shape, and secondly, the color presents an extremely shocking visual effect. Line modeling is not prominent in this period, so the lines are rustic and rough. At the same time, most of the lines are also completed by blending colors, so the colors are not like the scroll paintings of this period in China, which are purely outlined and filled with colors, but the colors, lines, and blocks are blended into one. Significantly influenced by the Shading and Highlighting Techniques of Hinduka, as well as limited access to pigments and many other factors, forming the outstanding characteristics of the murals of this period in terms of color. Because the lines themselves do not yet have the maturity of the Tang

Dynasty onwards, the expression of color becomes the most prominent visual effect, and the modeling is, to a large extent, also presented through the role of color.

Q4: What do you think about the visual effects of mural painting color?

A: First of all, from the practical point of view, color provides the most intuitive presentation and differentiation method for the content of mural paintings, and we can judge different object scenes such as characters, costumes, utensils, animals, mountains, rivers, trees and so on through color. As mentioned earlier, the presentation and differentiation of these scenes do not depend entirely on line modeling but rely heavily on color to present. Secondly, color also provides the most direct attraction to the believers and viewers regarding aesthetics and religious visual psychology, including the painters' constant retouching and filling of the murals, all of which make for excellent samples of color rendering. Of course, from today's point of view, the colors of the mural paintings of this period have also become precious historical materials for future generations to study the aesthetic fashions and coloring techniques of the time and explore their possible inspiration for today's and coming art. After all, this stage changes fashion enough to provide a reference for exploring future art.

Q5: Where do you think the uniqueness of the Mogao Caves mural paintings color?

A: On the one hand, Mogao Caves mural paintings' color and mainstream Chinese scroll paintings is very different; mainstream Chinese paintings more emphasis on the line for the bone, hook line color filling procedures, and not too much attention to color level changes, even if there is, more is also through the ink to complete. Moreover, mainstream Chinese painting attaches more importance to the lightness of ink and color, and after the Tang Dynasty, mainstream Chinese painting in terms of color is completely relegated to a secondary position. On the other hand, because the creation and acceptance of mainstream Chinese painting is the aristocrats and the literati, its admirers accept the Taoist idea of "doing nothing", so it has always pursued the implicit expression of the color, even Gu Kaizhi, the relatively early painters, such as his "Admonitions Scroll", the overall coloring is not heavy, the ink is still in a prominent position. The presentation of ink is still in a prominent position. Moreover, in terms of the medium of painting, mainstream Chinese painting is more likely to utilize the brush's

expression of linearity on silk and paper. All of these factors contribute to the difference between mainstream Chinese painting and Mogao Cave mural paintings. It is easier to understand the uniqueness of the colors of the Mogao Caves mural paintings when viewed in this way.

The colors of the mural paintings are more intense and thicker and distinctly show various technical styles, such as thick painting, overlapping dyeing, split dyeing, outlining and filling in colors and using colors as lines. In terms of the pigments used, the heavy cinnabar, stone green, and azurite present a very different character from that of mainstream Chinese paintings. As in mainstream Chinese painting lack of data to prove the "Shading and Highlighting Techniques", and "MoGu Technique", in the mural paintings also have a wealth of examples. Dunhuang differs from other caves and murals of the same type because of its regional specificity. For example, compared with the Xinjiang Kizil Caves, although the same Buddhist theme, the choice of colors and the use of effect are very different. Compared with the temples and caves in the Central Plains of China, the color difference between the two is even stronger.

Q6: What are the main aspects of the current research on the color of the Mogao Caves mural paintings?

A: The first step is to study the current status of colors and their changes. Through the color of the existing mural paintings, the study of color change and fading. This is because it is directly related to the original face of mural paintings' color and how it evolved into the present face, which can reflect the aesthetic choice and technique of the people at that time. This also involves the acquisition of pigments; for example, if we understand the use of different colors and changes in the situation, will we deduce that people at that time chose those colors? What were their principles of choice? Were the colors used out of necessity for the content of the picture, or were they used out of necessity due to objective constraints? Or both. Then it is logical to involve the mural painting archaeology and protection; after all, the color of the past law of change as well as possible future changes, are worthy of attention, to narrow the scope and speed of change of the mural paintings, it is necessary to summarize the past color changes in the law, more reasonable protection. The damage to the mural paintings is multifaceted, including microbial infringement and the impact on the natural environment. Due to the

characteristics of the mural paintings themselves, as well as the mural paintings in the development of history, will be covered or uncovered, and other man-made impacts, to more accurately grasp the situation of the mural paintings will also use X-ray to analyze the color.

Q7: Can you give some ideas for adapting the colors used in Mogao Caves mural paintings with current art and design works?

A: After such a long time of research and accumulation, the Mogao Caves have summarized a more systematic system in terms of color. Some researchers are already working on drawing and organizing the chromatograms. However, I think this system should not only stay in the past color of the chart collation; there should be more extension and expansion. Dunhuang mural paintings can still move and shock, still revitalized, which must have many living factors. The study of mural paintings should not only stay at the level of archaeology and restoration because, in terms of aesthetics, it is also a treasure trove; at least, I think it can be developed to expand the space very broadly. This is the second problem. Absorbing, inheriting, and recreating Dunhuang in the fields of art and design and in the field of life is the way to make Dunhuang mural paintings continue to be revitalized. The use of Dunhuang mural paintings in painting is nothing new, and many aspects of design and daily life have long been using Dunhuang elements. It is only in design and life that the absorption of the Dunhuang frescoes has been more in the form of direct copying of partial elements and a lack of more intrinsic creativity, which is an obvious shortcoming, but also an opportunity for more creativity. I am optimistic about the possible future impact of Mogao Caves mural paintings, or how they can be absorbed, inherited, and created more reasonably.

Expert 2

Nationality: Chinese

Position: Associate Professor

Specialties: Oil Painting, Mixed Media

Q1: In developing Mogao Caves mural paintings, what are the characteristics of this stage from the Northern Dynasties to the Tang Dynasty? What is the place of this stage in history?

A: The changes in mural painting during this period are exciting! In the Northern Dynasties, the paintings were more "wild," the colors were vibrant, and in some ways, they were pretty similar to oil paintings; the figures were very abstract, and there was a modernist style. It was utterly different, refined, and programmed in the Tang Dynasty, similar to today's commercial blockbusters. This period is critical, equivalent to the “adolescence” of Chinese mural painting, the perfect fusion of foreign and local styles, and later influenced the entire East Asian art circle.

Q2: Among the mural paintings from the Northern Dynasties to the Tang Dynasty, what mural contents are the most representative?

A: The Northern Dynasties loved to paint Buddhist stories, such as feeding tigers and nine-colored deer, in the style of comic strips. The Tang Dynasty upgrade, which can not be called upgraded, more like a fusion, began to paint a world of bliss and very grand scenes, with the current IMAX movie as shocking! The Sutra paintings, especially, are brilliant and dazzling.

Q3: In the content of these representative mural paintings, what do you think is the role of color in them? How is the importance of color reflected?

A: Color is very important, especially from our perspective as oil painting professionals; color is the first visual element. Just as you have to mix colors to make a movie now, the painters of that time understood this. Cold tones make you feel quiet and peaceful, and warm tones are immediately lively. The best thing is that they could separate the picture into front and back layers with color. We can separate the layers just like we can use computer software to draw.

Q4: What do you think about the visual effects of mural painting color?

A: I don't think it's out of date even now. Those color schemes in the mural can be taken out randomly to be the fashionable color of the year. But now the problem is that the market related to product homogenization is serious; if one sees too much, there is always a kind of visual fatigue feeling.

Q5: Where do you think the uniqueness of the Mogao Caves mural paintings color?

A: The special thing about color is that it is one of the beautiful elements in the picture, and the impactful colors will attract the viewer for the first time. The colors in Dunhuang mural paintings also play this role, and all those ancient believers who went to the grottoes to worship Buddha would also be attracted to the overall tone of the cave first.

Q6: What are the main aspects of the current research on the color of the Mogao Caves mural paintings?

A: For my specialty, I mainly focus on combining the elements of Dunhuang and oil painting; they are not the same culture. If you want to combine them, you must find their commonalities and characteristics, which is still tricky. If you don't integrate them well, you will feel a sense of separation.

Q7: Can you give some ideas for adapting the colors used in Mogao Caves mural paintings with current art and design works?

A: I don't know much about design, but it would be interesting to try using the mural's colors in an oil painting. But for now, it's all about using the color scheme directly from the mural; it's not precise, and most of the time, it's all about feeling and creating that atmosphere. And a lot of merchandise nowadays uses Dunhuang's color elements! Look at some brand bags now; don't they all love to use Dunhuang colors? Do game scenes; just copy a few color schemes. Home decoration can also be a little “Dunhuang red” with “grotto green,” very high sense! Many professional college and university students love to play with this, reinterpreting traditional colors with modern techniques.

Expert 3

Nationality: Japanese

Position: Associate Professor

Specialties: Artistic Theory

Q1: In developing Mogao Caves mural paintings, what are the characteristics of this stage from the Northern Dynasties to the Tang Dynasty? What is the place of this stage in history?

A: In the Mogao Caves, mural paintings were used during development, from the Northern Dynasties to the Tang Dynasty. I think the change in fossils is enormous. Northern Dynasties, the mural is relatively simple, the lines have a hard and straight feeling, and the color is not so rich; it mainly painted the Buddhist story, like some of the Buddha's life story, like giving up his body to feed the tiger. The character image is still fragile and has an ancient and majestic charm. To the Tang Dynasty, there is a significant reversal. The color scheme is a lot more, the line gradually becomes smooth and natural, and the characters are complete and rounded. I think this is still the Tang Dynasty, for the beauty of the relevant expression is not a mute feeling. Moreover, at this time, there were not only Buddhist stories but also many scenes reflecting the social life of the time. This stage in the history of the position is critical, such as the Tang Dynasty “Vimalakirti,” the picture is very grand, the Buddhist philosophy and artistic expression of a specific combination, is to show the Tang Dynasty painting art but also reflects the importance of the status of Buddhism at that time and influence. This stage should be said to be the peak of the development of the Mogao Caves murals.

Q2: Among the mural paintings from the Northern Dynasties to the Tang Dynasty, what mural contents are the most representative?

A: Because I am very interested in these Chinese murals, I have also visited China. I think this feeder mural content represents the Northern Dynasties to the Tang Dynasty murals. In the Northern Dynasties, the feeder statue was straightforward and relatively small, but it was very solemn and pious and could also be seen slowly. I see that, in some cases, the feeder statue is very tall, wearing clothes that are not complicated, and

the facial expression of how to say it is almost the same. However, the Buddha's reverence and dedication to the heart can still be felt. In the Tang Dynasty, the statues were fuller and taller, and the clothes they wore were a bit more ornate, and the prosperity of the Tang Dynasty can be detected. The prosperity of the Tang Dynasty can be detected in the south wall of the tunnel in Cave 130 of Mogao Cave, which shows the governor's wife and her dependents dressed in gorgeous clothes with a very confident and noble facial expression. Through these figures, we can learn about the social situation in China at that time, so this mural can still reflect many things.

Q3: In the content of these representative mural paintings, what do you think is the role of color in them? How is the importance of color reflected?

A: In the representative mural content, I think the color is to make the mural; that is, we see the mural at first glance, and there is a powerful visual impact and artistic influence. I took I have seen the Northern Dynasties period of murals; I think the time of the color variety is relatively short, but I still can see a unique use of color, such as the earth mentioned in the red and stone green, but also has an ancient and solemn feeling, obviously can feel the religious sense of sacredness. I think this color is essential to reflect the cultural connotations and spirit of different periods in China.

Q4: What do you think about the visual effects of mural painting color?

A: In my opinion, the visual effect of the color of the frescoes, I can say that in many different paintings that I have seen, this is very surprising to me. I will take my contact with some murals from the Northern Dynasties as an example. However, the color is effortless, such as red, green, black, and white. There is a very appropriate feeling, so the visual impact is simple. There is a kind of power there, straightforward. This Tang Dynasty murals began to become rich in color. Like this “playing the pipa figure,” the character's skin is very white, wearing clothes of color is also; in addition to this gold, green, and red color collection, the visual effect is bright, how say it, in today's words, it is the late spring wear on the body, flowers are all open together.

Q5: Where do you think the uniqueness of the Mogao Caves mural paintings color?

A: I think the uniqueness of the Mogao Grottoes mural color embodiment should be said to be multi-faceted. It has a unique religious color presence. Like the Northern Dynasties period of murals, it uses earth red, stone green, and lapis lazuli. These colors, such as in the Jātaka of Sattva Prince, use the earth red in the human skin; there is an effortless and solemn feeling when we look at the time; it will be associated with the sacredness of the religious story. To the Tang Dynasty, it is not the same. The level of color change is undeniable. I take the Amitabha Pure Land Transformation Figure; inside the gold, vermilion, and stone green, some of the more vibrant colors are used a lot, can be presented in a specific time frame of the Western Elysium, is more golden. There is also the unique contrast and matching of colors. Like in the Nine-Colored Deer Bunsen, this nine-colored deer is white, but when we look at it, we notice a point where the surroundings are dark, such a strong contrast that immediately brings out the image of the nine-colored deer.

Q6: What are the main aspects of the current research on the color of the Mogao Caves mural paintings?

A: My research is mainly on the symbolism of colors. In our country, cherry blossoms symbolize a short but beautiful life. The colors of cherry blossoms include pink and white and combinations of these colors. The Mogao Cave murals also have such colors; then, I will focus on the study of the combination of different colors and how they reflect each other to produce a unique visual effect, such as a combination of what is symbolism.

Q7: Can you give some ideas for adapting the colors used in Mogao Caves mural paintings with current art and design works?

A: The idea is still there. In Japanese anime design, you can borrow the color style of the Mogao Cave murals. For example, in the design of a fantasy adventure anime scene, the frescoes in the brighter gold, deep blue, and bright red used in such an atmosphere are more mysterious. There is also a mural in our country's tea set; you can refer to the Mogao Cave murals in the color of the collocation. For example, the mural will be stone green to embellish the pattern of the tea cups and then earthy yellow to decorate the tea tray so that it will be a different style. But then, because the value of the Mogao Grottoes

for China is significant, our country should still be careful to use them and not arbitrarily go to the combination.

Expert 4

Nationality: Chinese

Position: Associate Professor

Specialties: Graphic Design

Q1: In developing Mogao Caves mural paintings, what are the characteristics of this stage from the Northern Dynasties to the Tang Dynasty? What is the place of this stage in history?

A: Foreign style factors influenced the early murals of the Northern Dynasties period because he was the earliest from this Gandhara period; he influenced painting style more, including in many kinds of flying modeling or the naked upper body. A male expression, including the Buddha's kind of cross-footed Bodhisattva this kind of modeling, is not like the later cross-legged seated modeling. It was not a lot of influence from the Tang Dynasty, but the Chinese were more serious. For example, The Sutra paintings in the Tang Dynasty may be more of a kind, and the Tang Dynasty may have a larger format. The content of the painting of the world of bliss is a kind of yearning for the world of bliss. In terms of the background, it was relatively peaceful, and the people's lives were more stable. The status of the North Dynasty because of the entire Dunhuang mural early certainly by the foreign influence of the Western region, as well as the later Sinicization. However, we can see that the Tang Dynasty period, for Buddhism, is in relatively high esteem. So in this period, including not only from our embodiment from this mural, as well as in the Tang Dynasty, some of the construction of Buddhist temples, as well as in this period, including some of them having fiefdoms, from the policy level for the development of Buddhism also played a significant role in the role of.

Q2: Among the mural paintings from the Northern Dynasties to the Tang Dynasty, what mural contents are the most representative?

A: Because the early Jātaka stories paintings are mainly about inner spiritual practice, giving, and epiphany, actually more in the process of practicing through one's realization. I think this kind of mural is more representative.

Q3: In the content of these representative mural paintings, what do you think is the role of color in them? How is the importance of color reflected?

A: The Tang Dynasty was more ornate, fuller of detail, and more expressive of the image. Earlier mural paintings went through a more chaotic era and may not have been as mature. Later, as the mural developed, it became more mature in its form. In terms of the use of color, it was also constantly fleshed out.

Q4: What do you think about the visual effects of mural painting color?

A: Because of this now, we see a lot of Dunhuang this creative design, but in the eyes of the public, more flying sky, nine-colored deer, and other classic images. It has formed a stereotype; we all think Dunhuang is nothing more than these things, these representative symbols. In their perception, there's no more innovative development of this traditional culture. What have we done? We have not been able to achieve better innovation in the inheritance so that our culture can undergo a kind of living transformation. The design needs to be significantly changed and improved, as well as the homogenized expression of the market.

Q5: Where do you think the uniqueness of the Mogao Caves mural paintings color?

A: There must be because we may be more often concerned about its content and its form, and the color itself is a large part of our visual senses in the possession of a large part. Still, in this Dunhuang mural, we go to extract the time; on the one hand, we want to see that is to say that it is the existing color. Because the time is very long, oxidation and weathering will occur in the long-term process, so the color of its brightness will change. Then, in this process, have we not made a reduction? There is also a color transformation problem; it only provides a database, but in our practice, it also needs to be adjusted according to our specific practice.

Q6: What are the main aspects of the current research on the color of the Mogao Caves mural paintings?

A: This perception of color has to be explored with specific questions, such as whether we will do color restoration. Its color has been changed. The restoration of color is a

recognition of the painting itself. We can now see a lot of digital, such as digital Dunhuang, and we can see a lot of new technologies in the virtual space for the scene of the scene reconstruction. We can see more color in our mural through the high-definition filming to be presented. In this new environment, in this new possible exhibition, how is our color presentation for the public? Is it a presentation of the grottoes as they are today, or are they being restored through digital analysis and digital restoration?

Q7: Can you suggest ways to adapt the colors used in Mogao Caves mural paintings to current art and design works?

A: Anything has its design requirements. It is not that we can directly adopt it, now we use it through a copy and paste. I think in this process, including the color itself is for the use of classic colors, at the same time, there is also the use of color with a color, that is, we have different colors with the effect is not the same, so in this process, to reflect the penetration of traditional culture in modern design. At the same time, it also has its times in, because we can not bring his original. Then where is our innovation? So, combining some of the current mainstream art styles is better in this process, as well as the specific design.

Expert 5

Nationality: Chinese

Position: Associate Professor

Specialties: Visual Design

Q1: In developing Mogao Caves mural paintings, what are the characteristics of this stage from the Northern Dynasties to the Tang Dynasty? What is the place of this stage in history?

A: From our professional point of view, the Northern Dynasties to the Tang Dynasty Mogao Cave mural development can be said to have completed a magnificent metamorphosis. North Dynasty period murals are like a child learning to paint; the technique is still relatively young, with strong and bold colors and India and Persia obviously influence character modeling. You see, those flying sky, fit bodies still retain the apparent characteristics of the West. During the Tang Dynasty, mural art is entirely "grown-up." The most obvious change is from a single-story painting to the development of the magnificent painting of the sutra, just like from the novel upgraded to a long book.

Q2: Among the mural paintings from the Northern Dynasties to the Tang Dynasty, what mural contents are the most representative?

A: If I were to choose the most representative, I would say that Jātaka stories paintings, such as the famous "Nine-Colored Deer" story, represent the Northern Dynasties period. These paintings are like comic strips, dividing a complete story into several scenes. Their most important feature is their powerful religious meaning; all they talk about are self-sacrifice, karma, and retribution. In the Tang Dynasty, the most representative of these paintings was the Sutra painting, which showed the world of bliss described in the sutra.

Q3: In the content of these representative mural paintings, what do you think is the role of color in them? How is the importance of color reflected?

A: Color can be more than decoration in these mural paintings; it assumes a very important function. In the Jātaka stories paintings of the Northern Dynasties, intense color contrasts act like highlighters to highlight key episodes. In the Sutra paintings of the Tang Dynasty, the role of color was even richer. It is especially worth mentioning that the painters knew how to use color to guide the line of sight, such as warm tones to bring out the central Buddha statue and cool tones to push away the background, a technique we still use in our designs today.

Q4: What do you think about the visual effects of mural painting color?

A: The color effects of these mural paintings have weathered over a thousand years, but many of the colors are still vibrant and vivid. The colors of the Northern Dynasties period have a strong visual effect of mineral pigments such as stone green and stone green on an extensive earthy red background. Painters in the Tang Dynasty were particularly adept at shaping three-dimensionality with gradations of similar colors; for example, a single garment might use five or six shades of green to show folds, light, and shadow.

Q5: Where do you think the uniqueness of the Mogao Caves mural paintings color?

A: The uniqueness of the Mogao Cave colors lies in the fact that the painters do not simply apply the pigments but rather layer the different mineral pigments on top of each other. For example, suppose you want to paint a leaf. In that case, you might apply a layer of base color, then cover the dye with translucent color, and finally, point highlights so that the effect becomes particularly textured.

Q6: What are the main aspects of the current research on the color of the Mogao Caves mural paintings?

A: Now, scholars on the Mogao Cave color research are mainly focused on several aspects: first of all, pigment analysis, with X fluorescence spectroscopy of these high-tech means, to figure out what the ancients in the end with which mineral pigments, how the proportion. This work is very important because many colors now look entirely different from the original, such as lead oxide, which will turn black. Second is the color

restoration research, that is, through digital technology, to restore the original color effect of the mural.

Q7: Can you suggest ways to adapt the colors used in Mogao Caves mural paintings to current art and design works?

A: As a designer, the most important thing to learn from the Mogao Cave colors is its color system. For example, the Tang Dynasty's “green landscape” with gold leaf can be translated into modern Chinese design. A recent branding project I worked on drew on the contrast between stone green and earth red in the mural, which is both traditional and modern. -48 Rows Another way to think about it is to learn its color hierarchy. We often use a flat style for UI design, but you can try layering multiple layers of semi-transparent colors to create a richer texture, like in the mural. There is also the use of gold, not necessarily with real gold foil; you can use the stamping process or gold ink so that the design retains the traditional flavor but is also in line with modern aesthetics.

Expert 6

Nationality: Japanese

Position: Associate Professor

Specialties: Art and Design

Q1: In developing Mogao Caves mural paintings, what are the characteristics of this stage from the Northern Dynasties to the Tang Dynasty? What is the place of this stage in history?

A: I do art and design, but I've always been fascinated by the Mogao Caves mural paintings. The mural changes from the Northern Dynasty to the Tang Dynasty are apparent. North Dynasty, the influence of Buddhism, the mural color rustic, the character lines hard, rough style, like can hear the old religious stories in the ear. During the Tang Dynasty, the murals changed significantly. They became gorgeous, especially with bright colors, characters rounded and packed, and gestures dynamic and full of life. The look is excellent. Tang Dynasty should have a look. This period in history is too critical; Buddhist art and local cultural integration and development from the beginning to the later generations of mural art lay a good foundation. The North Dynasty started the integration of the first, and the Tang Dynasty reached the peak of art, leaving us so many valuable assets. I engage in creating art and can find inspiration from it; I usually do design, but also often from these murals to pull elements, which is super helpful.

Q2: Among the mural paintings from the Northern Dynasties to the Tang Dynasty, what mural contents are the most representative?

A: Northern Dynasty to the Tang Dynasty murals, Buddhist murals that are quite prominent, such as the Dunhuang Mogao Caves, are too shocking! In Buddhist murals in the Northern Dynasties, the characters look thin and straightforward, and the harsh lines and colors are also exquisite. Waiting for the Tang Dynasty, Buddhist murals are even more cattle. The characters are rounded and full-bodied, the color is gorgeous, and the technique is more mature. Say 172 caves of the “View of Infinite Life Sutra Painting,” the world of bliss painted with the fairyland no different, inside the characters, buildings, and scenery; every place is painted super detailed, feel a look into the world as if. These

murals are beautiful works of art and show the social situation and people's beliefs at that time. They are handy for those of us engaged in art and design, and we can learn the tricks of color matching and composition from them when we are doing design.

Q3: In the content of these representative mural paintings, what do you think is the role of color in them? How is the importance of color reflected?

A: Color is crucial in Buddhist murals from the Northern Dynasties to the Tang Dynasty. Take the Tang Dynasty Cave 172's "View of Infinite Life Sutra Painting," for example; those gorgeous colors instantly bring out the gorgeousness of the Elysium. You see, the Buddha's robe, the Buddha's light with red, orange, these warm colors, the Buddha immediately looks solemn and sacred, as if it comes with a halo, so people can not help but stare, the heart is full of awe. The sky and the lotus pond are blue and green, and these cold colors immediately create a quiet, peaceful atmosphere that feels like a fairyland. Bodhisattva's face is painted pink, looking exceptionally soft and compassionate; their demeanor and temperament are highlighted. North Dynasty murals, although the colors are lighter, simply with a little, can also reflect the ancient, solemn style. In short, the colors make the scenes and characters in the murals come alive. Without color, these murals are certainly not so attractive; religious mystery and solemnity can not be conveyed, and there can be too much color!

Q4: What do you think about the visual effects of mural painting color?

A: From the Northern Dynasty to the Tang Dynasty murals, the visual effect of color is simply stunning! Dunhuang murals, the Northern Dynasties at that time, although the color is simple and rustic, the earth red and stone green with a match, the contrast is extreme, and the picture will have a tension. Even after thousands of years, we look at the time and can still feel that simple beauty. In the Tang Dynasty, colors became rich and gorgeous. In some of the sutra paintings, the backlight of the Buddha and the details of his costume are depicted in gold, together with the bright colors of red, bright yellow, and dark blue; the whole picture is golden and brilliant, with a substantial visual impact. The color transition is particularly natural; the character's skin and clothing color levels are vibrant, and the characters are like living and feel ready to come out of the mural. So grand scene, so exquisite color, who can not be attracted to see? Every time I

appreciate it, it is like enjoying a visual feast, and I can find a lot of artistic inspiration from it just by looking at it, which is fantastic!

Q5: Where do you think the uniqueness of the Mogao Caves mural paintings color?

A: Mogao Caves mural paintings of color that uniqueness can be too evident. First of all, it carries a strong historical flavor. After thousands of years, the color is a little mottled, but the traces left by the years, in turn, give the murals a kind of rustic beauty. Early frescoes faded, dulled down the tone, look more mysterious. Plus, color matching, especially a set. It will use contrasting colors to highlight the main body, like painting a big red Buddha, and then with a green background, all of a sudden, to catch the eye, the visual impact is super strong. Also, Mogao Grottoes mural color fusion of many cultural elements. Our cultures like to use the Central Plains' color and the Western culture's shadow. For example, using blue and purple is a characteristic of the Western region. With so many cultures together, the connotation of the mural color is rich, and the style is unique. In the art world, the Mogao Caves mural paintings, with these colors, have steadily occupied a place for us to engage in art and design; this is a treasure trove of fabulous inspiration.

Q6: What are the main aspects of the current research on the color of the Mogao Caves mural paintings?

A: The current research on the color of Mogao Caves mural paintings mainly comes from these aspects. First, regarding the pigment composition, we must figure out what the ancients used minerals and vegetable pigments, like vermilion, stone, and green, to understand their color source. Then is the evolution of color. Mural paintings, over time, are affected by the environment; the color will fade and discoloration. Studying these changes helps protect and restore murals. There is also the cultural connotation of color. In Buddhist culture and society at that time, different colors have different symbolic meanings; for example, red may represent solemnity and auspiciousness. Finally, there is the painting technique. Ancient people's means of mixing and applying colors are compelling, making the color layers rich and the transition natural, such as the haloing method. These studies have many benefits for us in art and design. It allows us to learn

the color wisdom of the ancients and then cleverly apply these to modern design to add color to the work.

Q7: Can you suggest ways to adapt the colors used in Mogao Caves mural paintings to current art and design works?

A: Several ideas exist for incorporating Mogao Grottoes' fresco colors into modern art design. We can refer to the mural color scheme when designing posters or graphic design. For example, a music festival poster can use the red and green colors of the frescoes, which is particularly retro and eye-catching, and this strong contrast can show the passion and vitality of the music very well. This piece's interior design is quite good, from the mural's light color palette to draw inspiration. Like light blue and beige, used to create a tea room space, can create a peaceful and Zen atmosphere so that people in a fast-paced life can feel simplicity and leisure. Stylish designs can also incorporate mural elements. Combine the golden lines of a mural with clothing to create a fabulous evening gown. With gold accents on a plain background, attending an event with a classical flavor is gorgeous and unique. Doing this will revitalize the ancient colors of the frescoes in modern art and design, add cultural heritage to contemporary works, and make the design more tasteful.

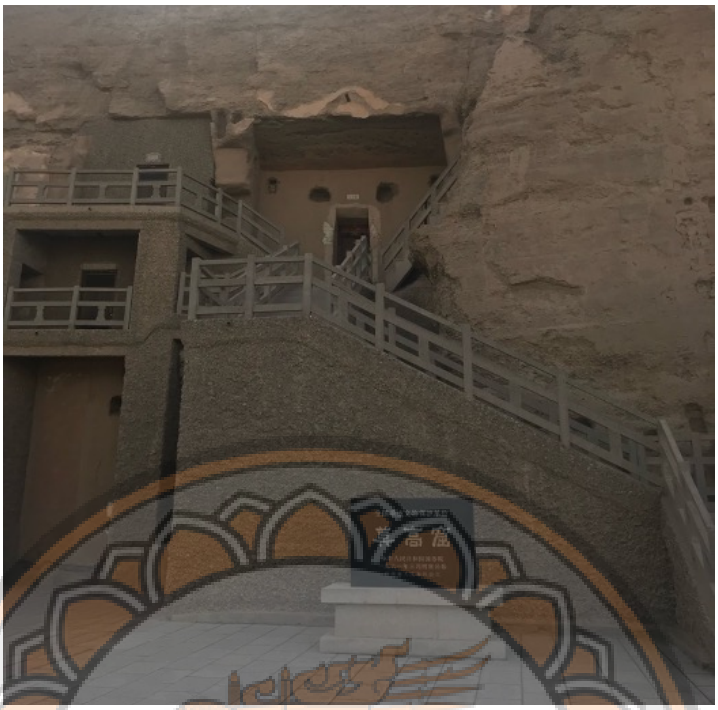
APPENDIX B FIELDWORK PHOTOS

Cave 96 "The Nine Layered Tower"

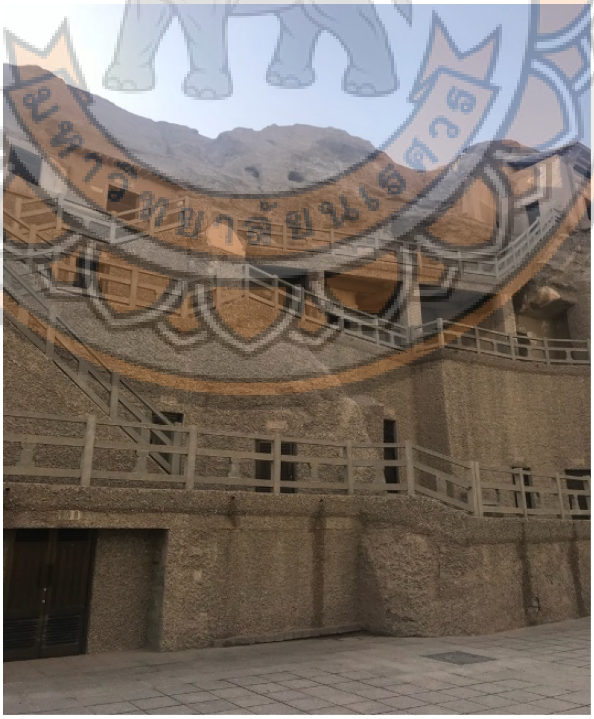
Outside the Gate of Cave 96

Cave 231 and the Mural Outside the Door

Mural Outside the Door of Cave 231 (Partial)



Tablet Inscribed with the Name of Mogao Cave

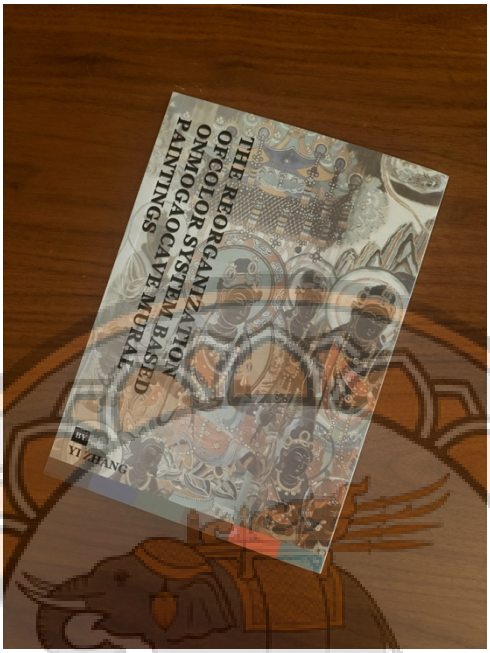


Distribution of Caves

Caves 16-17 Sutra Cave Exterior

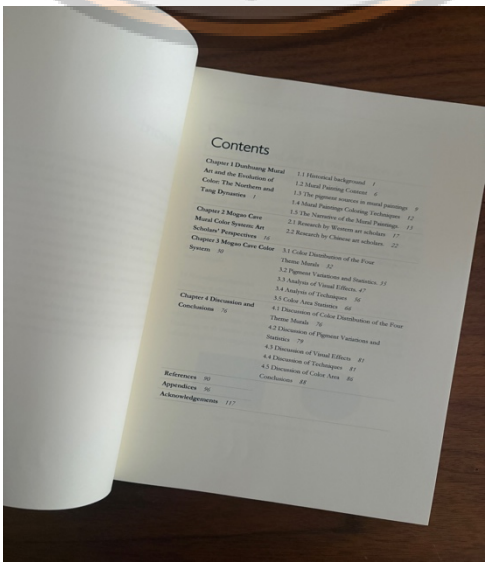
Cave Gate Sign and QR Code for Explanation

APPENDIX C BOOK PRESENTATION




THE REORGANIZATION
COLOR SYSTEM BASED
MOGAO CAVE MURAL
PAINTINGS


THE REORGANIZATION OF
COLOR SYSTEM BASED ON
MOGAO CAVE MURAL
PAINTINGS
YI ZHANG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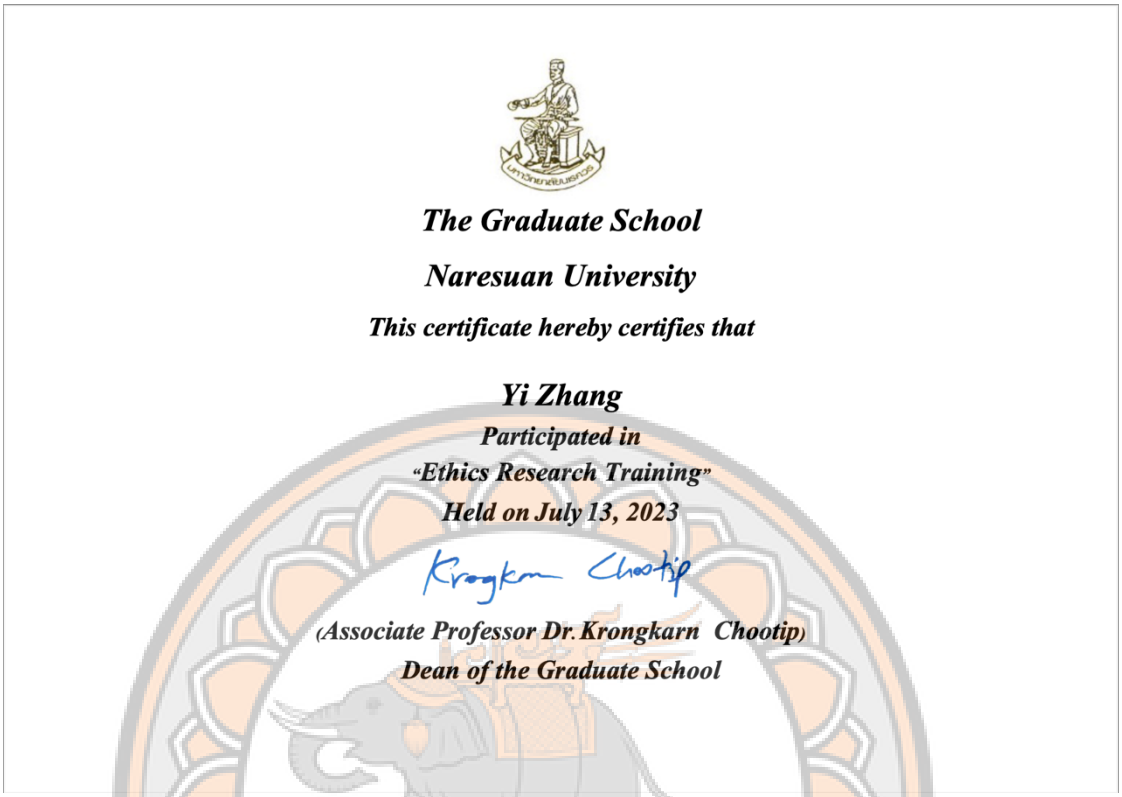

The Graduate School

Naresuan University

This certificate hereby certifies that

Yi Zhang

Participated in

"Ethics Research Training"

Held on July 13, 2023

Krongkarn Chootip

(Associate Professor Dr. Krongkarn Chootip)

Dean of the Graduate School

NO. 2605179

RIIE RESEARCH AND INNOVATION INSTITUTE OF EXCELLENCE WALAILAK UNIVERSITY

GRAD COLLEGE OF GRADUATE STUDIES WALAILAK UNIVERSITY

CERTIFICATE

OF PARTICIPATION

Human Research Ethics Committee of Walailak University
certifies that

Yi Zhang

Has Completed the Online Research Ethics Training Course

"The Human Subject Protection Training"

Completion Date: 26 May 2024 Expiration: 25 May 2026

Chuchard Punsawad

(Associate Professor Chuchard Punsawad Ph.D)
Chairman of the Ethics Committee in Human Research
Walailak University

S. Panichkul

(Colonel Associate Professor Suthee Panichkul)
Chairman of the Forum for Ethical Review Committee
in Thailand (FERCIT)

Announcement

The Graduate School, Naresuan University

Appointment of thesis Advisory Committee

for Doctoral Degree Program

.....

Following the principle of the Office of the Higher Education Commission and Naresuan University Rules and Regulations for Graduate Student 2016. The Graduate School announces the appointment of Thesis advisory committee for Doctoral degree program. The committee for **Mrs.Yi Zhang**, student ID: 65031580 in Doctor of Fine and Applied Arts Program in Art and Design consists of the following names:

1. Assistant Professor Dr. Thirawut Bunyasakseri Advisor

Announced date: July 11, 2024

(Associate Professor Dr. Krongkarn Chootip)

Dean of the Graduate School, Naresuan University

Announcement of Faculty of Architecture Art and Design
Appointment of Thesis Proposal Committee
Doctor of Fine and Applied Arts Program in Art and Design

.....

To consider the thesis proposal of Doctor's Degree of Doctor of Fine and Applied Arts Program in Art and Design, thesis proposal outline should be in order and efficient manner. Therefore, by virtue of Section 26 of Naresuan University as an act of legislation 1990, which will consider the thesis proposal of **Mrs.Yi Zhang**, the committee consists are following:

1. Asst.Prof.Dr.Thirawut Bunyasakseri	Chairperson
2. Assoc.Prof.Dr.Thaveerat Promrat	Committee
3. Assoc.Prof.Dr.Tatiya Theppituck	Committee and Secretary

The Committee shall conduct the examination of the thesis proposal of **Mrs.Yi Zhang.** On Tuesday August 20, 2024, Faculty of Architecture Art and Design from 1:00 p.m. Chairperson of the committee will consider the thesis proposal's results which should be sent to the Faculty of Architecture Art and Design. Faculty of Architecture Art and Design will take the next process.

Announced on August 19, 2024

Nirat Soodsang

(Assoc.Prof.Dr.Nirat Soodsang)
Dean of Faculty of Architecture Art and Design

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บัณฑิตวิทยาลัย มหาวิทยาลัยนเรศวร The Graduate School, Naresuan University

แบบอนุมัติผลการพิจารณาโครงร่างวิทยานิพนธ์ Thesis Proposal Approval Form

คณะกรรมการพิจารณาโครงร่างวิทยานิพนธ์ของ (นาย, นาง, นางสาว) ...... Mrs.Yi Zhang ....รหัสประจำตัว ......65031580....
The Advisory Committee of: (Mr., Mrs., Miss): Student ID:

นิสิตระดับ / Level of Study:

☐ ปริญญาโท / Master's Degree — ○ แผน ก แบบ ก 1 / แผน 1 ว. 1 (Type A 1) ○ แผน ก แบบ ก2 / แผน 1 ว. 2 (Type A 2)

☐ ปริญญาเอก / Doctoral Degree — ○ แบบ 1.1 / แผน 1.1 (Type 1.1) ○ แบบ 1.1 / แผน 1.2 (Type 1.2) ○ แบบ 1.1 / แผน 2.1 (Type 2.1) ○ แบบ 1.1 / แผน 2.2 (Type 2.2)

สาขาวิชา .... Art and Design .... คณะ/วิทยาลัย........... Architecture Art.and.Design.............
Field of study: Faculty/College:

ชื่อโครงร่างวิทยานิพนธ์ (ตามที่ระบุในประกาศฯ แต่งตั้งคณะกรรมการสอบพิจารณาโครงร่างวิทยานิพนธ์)
Thesis proposal Title

The Reorganization of Color Theory Based on Mogao Caves Mural Paintings

ได้พิจารณาโครงร่างวิทยานิพนธ์แล้ว
Result of the thesis proposal examination:

☑ อนุมัติ
Approved

☑ **เห็นสมควรปรับปรุง** (กรณีมีการเปลี่ยนแปลงชื่อโครงร่างวิทยานิพนธ์ โปรดระบุให้ชัดเจน) ดังนี้
With (minor, major adjustment); Reason:
- ปรับวัตถุประสงค์ให้เหมาะสมกับชื่อหัวเรื่องเล็กน้อย

☐ ไม่อนุมัติ เนื่องจาก
Disapproved; Reason:

(ลงนาม) .... ประธานกรรมการ
Signature Chair of the Thesis Proposal Exam Committee
(Asst.Prof. Dr.Thirawut Bunyasakseri)

(ลงนาม) .... กรรมการ
Signature Committee Member
(Assoc.Prof.Dr.Thaveerat Promrat)

(ลงนาม) .... กรรมการและเลขานุการ
Signature Committee Member and Secretary
(Assoc.Prof.Dr.Tatiya Theppituck)

<u>หมายเหตุ</u> กรุณากรอกข้อความด้วยเครื่องพิมพ์หรือคอมพิวเตอร์ Note: Complete this form using a computer and print.

Announcement

The Graduate School, Naresuan University

Approval of Thesis Proposal to Conduct Research

No. 015/2025

The Graduate School approved **Mrs.Yi Zhang**, student ID: 65031580; Doctor of Fine and Applied Arts Program in Art and Design, to conduct research. The approved thesis proposal entitled: **"THE REORGANIZATION OF COLOR SYSTEM BASED ON MOGAO CAVE MURAL PAINTINGS"** with Assistant Professor Dr.Thirawut Bunyasakseri as the thesis advisor.

When conducting research involving Research Ethics for Human Subjects, Research Ethics for the Use of Laboratory Animals, or Research Ethics on Biosafety, it is mandatory to obtain approval from the relevant committee. Research activities in these areas may commence only after receiving the necessary approvals.

Announced date: February 3, 2025

(Associate Professor Dr. Krongkarn Chootip)
Dean of the Graduate School, Naresuan University

COA No. 008/2025
IRB No. P2-0349-2567

คณะกรรมการจริยธรรมการวิจัยในมนุษย์ มหาวิทยาลัยนเรศวร
99 หมู่ 9 ตำบลท่าโพธิ์ อำเภอเมืองพิษณุโลก จังหวัดพิษณุโลก 65000 หมายเลขโทรศัพท์ 05596 ....

หนังสือรับรองโครงการวิจัยครั้งแรก

คณะกรรมการจริยธรรมการวิจัยในมนุษย์ มหาวิทยาลัยนเรศวร

ดำเนินการให้การรับรองโครงการวิจัยตามแนวทางหลักจริยธรรมการวิจัยในคนที่เป็นมาตรฐานสากล ได้แก่ Declaration of Helsinki, The Belmont Report, CIOMS Guideline และ International Conference on Harmonization in Good Clinical Practice หรือ ICH-GCP

ชื่อโครงการ : The Reorganization of Coloring System Based on Mogao Cave Mural Paintings
ผู้วิจัยหลัก : Mrs.YIZHANG
สังกัดหน่วยงาน : คณะสถาปัตยกรรมศาสตร์ ศิลปะ และการออกแบบ
วิธีทบทวน : แบบเร่งรัด
อาจารย์ที่ปรึกษา : ผศ.ดร.ธีรวุฒิ บุญยศักดิ์เสรี
สังกัดหน่วยงาน : คณะสถาปัตยกรรมศาสตร์ ศิลปะและการออกแบบ
รายงานความก้าวหน้า : ส่งรายงานความก้าวหน้าอย่างน้อย 1 ครั้ง/ปี หรือส่งรายงานฉบับสมบูรณ์หากดำเนินโครงการเสร็จสิ้นก่อน 1 ปี

เอกสารรับรอง

1. IF 01 Research Ethical Application for Non-Intervention Study เวอร์ชั่น 3.0 วันที่ 21 ธันวาคม 2567
2. IF 02 Conflict of Interest and Funding Form เวอร์ชั่น 1.0 วันที่ 12 กันยายน 2567
3. IF 03 (For Participants Aged 18 and Above) เวอร์ชั่น 3.0 วันที่ 21 ธันวาคม 2567
4. IF 03 Chinese Version (For Participants Aged 18 and Above) เวอร์ชั่น 2.0 วันที่ 11 ตุลาคม 2567
5. IF 04 (For Participants Aged 18 and Above) เวอร์ชั่น 3.0 วันที่ 21 ธันวาคม 2567
6. IF 04 Chinese Version (For Participants Aged 18 and Above) เวอร์ชั่น 2.0 วันที่ 11 ตุลาคม 2567
7. IF 05 CV Principal Investigator เวอร์ชั่น 1.0 วันที่ 12 กันยายน 2567
8. IF 06 Budget เวอร์ชั่น 1.0 วันที่ 12 กันยายน 2567
9. Full Protocol เวอร์ชั่น 3.0 วันที่ 21 ธันวาคม 2567
10. Guidelines for Interview Questions เวอร์ชั่น 3.0 วันที่ 21 ธันวาคม 2567
11. Guidelines for Interview Questions (Chinese Version) เวอร์ชั่น 3.0 วันที่ 21 ธันวาคม 2567

นักวิจัยทุกท่านที่ผ่านการรับรองจริยธรรมการวิจัยต้องปฏิบัติดังต่อไปนี้

1. ดำเนินการวิจัยตามที่ระบุไว้ในโครงการวิจัยอย่างเคร่งครัด
2. ใช้เอกสารแนะนำอาสาสมัคร ใบยินยอม (และเอกสารเชิญเข้าร่วมวิจัยหรือใบโฆษณาถ้ามี) แบบสัมภาษณ์ และหรือแบบสอบถาม เฉพาะที่มีตราประทับของคณะกรรมการจริยธรรมในมนุษย์ มหาวิทยาลัยนเรศวรเท่านั้น และส่งสำเนาเอกสารดังกล่าวที่ใช้กับผู้เข้าร่วมวิจัยจริงรายแรกมาที่คณะกรรมการจริยธรรมการวิจัยในมนุษย์ เพื่อเก็บไว้เป็นหลักฐาน
3. รายงานเหตุการณ์ไม่พึงประสงค์ร้ายแรงที่เกิดขึ้นหรือการเปลี่ยนแปลงกิจกรรมวิจัยใด ๆ ต่อคณะกรรมการจริยธรรมการวิจัยในมนุษย์ มหาวิทยาลัยนเรศวร ภายในระยะเวลาที่กำหนดในวิธีดำเนินการมาตรฐาน (SOPs)
4. ส่งรายงานความก้าวหน้าต่อคณะกรรมการจริยธรรมการวิจัยในมนุษย์ ตามเวลาที่กำหนดหรือเมื่อได้รับการร้องขอ
5. หากการวิจัยไม่สามารถดำเนินการเสร็จสิ้นภายในกำหนด ผู้วิจัยต้องยื่นขออนุมัติใหม่ก่อน อย่างน้อย 1 เดือน
6. หากผู้วิจัยส่งรายงานความก้าวหน้าหลังใบรับรองหมดอายุ และยังไม่ได้ใบรับรองฉบับใหม่ ผู้วิจัยจะต้องหยุดดำเนินการวิจัยส่วนที่เกี่ยวข้องกับการรับอาสาสมัครใหม่ นับตั้งแต่หลังวันใบรับรองหมดอายุจนกว่าจะได้รับใบรับรองฉบับใหม่
7. หากการวิจัยเสร็จสมบูรณ์ผู้วิจัยต้องแจ้งปิดโครงการตามแบบฟอร์มของคณะกรรมการจริยธรรมในมนุษย์ มหาวิทยาลัยนเรศวร

*รายชื่อของคณะกรรมการจริยธรรมการวิจัยในมนุษย์ (ชื่อและตำแหน่ง) ที่เข้าร่วมประชุม ณ วันที่พิจารณารับรองโครงการวิจัย (หากร้องขอล่วงหน้า)

ลงนาม:.....

(รองศาสตราจารย์ ดร.ศิริลักษณ์ ธีระภูธร)

ประธานคณะกรรมการจริยธรรมการวิจัยในมนุษย์

มหาวิทยาลัยนเรศวร

วันที่รับรอง : 8 มกราคม 2568

วันหมดอายุ : 8 มกราคม 2569

ทั้งนี้ การรับรองนี้มีเงื่อนไขดังที่ระบุไว้ด้านหลังทุกข้อ (ดูด้านหลังของเอกสารรับรองโครงการวิจัย)