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Analysis of the Composition and Change of Chinese Blue and White Porcelain Pot Glaze from the Perspective of Archaeology

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ABSTRACT

In order to deeply study the main components, appearance, whiteness and change process of Chinese blue and white porcelain glaze, 21 pieces of porcelain excavated in the Great Shangqing Palace of Longhu Mountain in Jiangxi Province in 2014~2017 were studied as the research objects, and electron microscope, energy dispersion scanner and main component analysis method were used to analyze and compare blue and white porcelain tire glaze. The results showed that the silicon, aluminum and other components of blue and white porcelain tire glaze were similar to those of the Hutian kiln and Fanchang kiln in the Song Dynasty (AD 1018~1032), and the shape and color were also similar. Among them, the silicon and aluminum content of 21 pieces of porcelain gradually increased, and the width of the bowl mouth gradually increased. This shows that at the end of the Song Dynasty (AD 1028~1032), the shape and technology of blue and white porcelain were upgraded and changed, and gradually showed the characteristics of the early Qing Dynasty (AD 1042~1052). The blue and white porcelain excavated by the Great Shangqing Palace of Longhu Mountain has historical and cultural value for exploring the porcelain-making technology, porcelain design and excavation of ancient Chinese blue and white porcelain, and the ancient city's ruins.

Keywords: Archaeology, Blue and White Porcelain Pot, Glaze, Constitute, Change Analysis.

INTRODUCTION

As the main product of the official kiln of Tang Mingqing (AD 985~1052), blue and white porcelain has representative craftsmanship, shape and glaze composition, which has essential archaeological value for studying porcelain characteristics and artistic design at that time. However, the previous blue and white porcelain research was mainly based on the theoretical comparison of shape and color and lacked the study of modern testing equipment. Some scholars believe that the blue and white porcelain during the Song Dynasty (AD 1023~1035) has a similar shape (Ahimbisibwe, Byamugisha, Mukasa, Omara, & Ntambi, 2022), but the content of aluminum in the composition of the tire glaze is increased. Some scholars believe that during the early Qing Dynasty (AD 1045~1058), the proportion of silicon elements in blue and white porcelain gradually decreased. This shows that previous theoretical studies lack quantitative analysis methods and cannot explain the evolution process of blue and white porcelain and the development of shape and color more in-depth (Colomban, Gironda, Edwards, & Mesqui, 2022). With the development of modern light and shadow technology, simulation technology, and intelligent algorithms, blue and white porcelain archaeological research needs more accurate monitoring methods. Therefore, this paper takes the site of the Great Shangqing Palace of Longhu Mountain as an example to study, revealing the changes in the composition of blue and white porcelain tire glaze. This paper first introduces the research significance of blue and white porcelain and Chinese blue and white porcelain pots in archaeology. Subsequently, the blue and white porcelain samples excavated from the ancient city site of the Qing Palace were described in detail, and the composition of the glaze was analyzed by scientific methods such as microstructure

analysis and energy dispersive X fluorescence spectroscopy (Panagopoulou, Lampakis, Christophilos, Beltsios, & Ganetsos, 2018). Combined with the appearance characteristics and whiteness value of the glaze, it is revealed that the sample belongs to a typical southern blue and white porcelain, and it is speculated that it may have been produced in the Hutian kiln in Jingdezhen in the Song Dynasty (AD 1018~1032). Then, principal component analysis was used to compare the chemical composition of the samples of the ancient city of Qing Palace with the southern blue and white porcelain glazes in the surrounding area and analyze their similarities and differences. Finally, this paper discusses the significance of the research results for the production process and trade circulation of blue and white porcelain and looks forward to the direction and value of further research. Through the in-depth analysis of the composition and changes of blue and white porcelain glaze, this study is of great significance in exploring the porcelain-making process (Ma, Pollard, Jiang, & Weng., 2021), porcelain trade circulation and historical and cultural background of ancient Chinese blue and white porcelain. Through the synthesis of archaeology, scientific analysis and historical documents, the rich connotation and far-reaching influence of Chinese blue and white porcelain will be further revealed, and the historical and cultural value of ancient sites related to blue and white porcelain will be excavated and protected. This will help to enhance the understanding of ancient Chinese culture and promote the development of porcelain research.

BLUE AND WHITE PORCELAIN AND ARCHAEOLOGICAL RESEARCH SIGNIFICANCE

History and Characteristics of Blue and White Porcelain

The Historical Background of Blue and White Porcelain

Blue and white porcelain, as a particular type of traditional Chinese porcelain, originated in the Tang Dynasty (AD 707~983), flourished in the Song Dynasty (Northern Song Dynasty AD 960-1126, Southern Song Dynasty AD 1127-1280), and reached its peak during the Ming and Qing dynasties (AD 1349~1836). It is famous all over the world for its beloved cyan ornament. The emergence of blue and white porcelain marked an essential breakthrough in Chinese porcelain craftsmanship and profoundly impacted porcelain production in later generations (Akpenpuun et al., 2021).

The Characteristics of Blue and White Porcelain

Glaze and color: The glaze of blue and white porcelain usually appears bright white, characterized by blue and white patterns painted on the surface of the porcelain. This cyan color is produced by a chemical reaction at high temperatures of the cobalt element added during the decoration stage. The cyan pattern of blue and white porcelain can present a variety of ways, styles and themes.

Technique and decoration: Blue and white porcelain decoration is usually done by hand. Decorators would first draw contours on the porcelain's surface, then fill it with blue and white paints for painting. The decorative styles of blue and white porcelain are diverse (Casimiro & Gomes, 2022), including traditional patterns of flowers and birds, landscapes, figures, geometry, etc., as well as foreign Islamic, Persian, Dutch and other styles. This unique decorative technique and various patterns make blue and white porcelain a vital part of Chinese porcelain culture.

Kiln mouth and process: Blue and white porcelain production is mainly concentrated in important kiln mouths in southern China, such as Jingdezhen (Colomban et al., 2021), Yixing, Porcelain Zhou and other places. Different kilns' blue and white porcelain has its characteristics and styles. Jingdezhen is one of the leading producers of blue and white porcelain, and its Hutian kiln blue and white porcelain is famous for its fine paintings, pure glaze and high-quality quality. People love Yixing's blue and white porcelain for its natural and superficial characteristics. Blue and white porcelain production includes clay preparation, molding, primary firing, decoration, painting, and secondary firing, each requiring experienced artisans to master and operate (Colomban, Ngo, Edwards, Prinsloo, & Esterhuizen, 2022).

Blue and white porcelain has become one of the essential representatives of Chinese porcelain culture with its unique cyan pattern and exquisite craftsmanship. It has a long history and diverse decoration styles and is favored by collectors and art lovers at home and abroad for its unique charm. The emergence of blue and white porcelain is a brilliant achievement of traditional Chinese ceramic craftsmanship but also one of the critical heritage of ancient Chinese civilization (Doger & & Maktal Canko, 2021).

The Role of Archaeology in the Study of Blue and White Porcelain

Archaeology plays a vital role in studying blue and white porcelain, revealing its production process, historical background and cultural significance with its unique methods and means. Here are a few main aspects of archaeology in blue and white porcelain research.

Reveal the production process and technical level: By analyzing blue and white porcelain tread, glaze and painting technology, archaeology can infer ancient production technology's technical details and level. For example, by studying the composition of porcelain glaze and the technique of illustration, it is possible to understand the raw materials used in the production process, the firing temperature, and the decoration process (Greer & MacDonald, 2022). This helps to understand the technical abilities and development of the craftsmanship of ancient ceramics.

Excavation of historical and cultural information: Blue and white porcelain is a work of art and carries rich historical and cultural knowledge. Archaeology excavates the sites and artifacts of blue and white porcelain to understand the age, origin, extent of its dissemination, and association with other cultural elements. The archaeological study of blue and white porcelain can reveal the production characteristics and style changes under different historical periods, regions and cultural traditions, which helps understand ancient social and economic exchanges, cultural integration and technological inheritance (Habicht-Mauche, 2022).

Research on porcelain trade and circulation: Blue and white porcelain is an important export commodity of ancient China's foreign exchange. Archaeologists can understand its circulation, trade routes and influence on domestic and foreign trade by discovering and studying blue and white porcelain. Through the analysis of the specific characteristics and production processes in blue and white porcelain samples, its possible origin and circulation range can be judged, further revealing ancient trade networks and economic ties (Kurzenkova & Kurzenkov, 2021).

Preservation and protection of cultural heritage: The archaeological research of blue and white porcelain also provides an essential basis for protecting and restoring cultural heritage. Through excavating blue and white porcelain sites and protecting cultural relics, archaeology can provide a scientific basis and methods for the protection of cultural heritage. In addition, the study of blue and white porcelain can also provide an essential reference for the identification, restoration and exhibition of collections.

Archaeology plays an essential role in the study of blue and white porcelain. Through archaeological methods and technical means, the cultural and artistic value of blue and white porcelain can be comprehensively revealed from the aspects of production technology, historical background, trade and circulation. This provides us with important clues and perspectives for a deeper understanding and appreciation of ancient porcelain.

COMPREHENSIVE CHARACTERISTIC ANALYSIS OF BLUE AND WHITE PORCELAIN SAMPLES FROM THE ANCIENT CITY OF QING PALACE

Methods and Materials

Research Methods

This paper mainly studies the blue and white porcelain excavated in the Shangqing Palace and uses DSF-60 spectroscopy scanner (desktop type), Niton Niton spectrometer (handheld), Mintab data analysis software, and Matlab simulation software for sample analysis. The analysis of 21 pieces of excavated blue and white porcelain shows the distribution of each porcelain, as shown in Table 1.

Table 1. Distribution of Blue and White Porcelain in Shangqing Palace

Location	Number of Pieces (pcs)	Numbering
Northwest corner	8	1, 2, 3, 8, 11, 20, 16, 17
Zhengxi	3	4, 5, 14
Southwest	4	6, 7, 10, 9
Southeast	2	13, 15
Northeast	4	18, 19, 21, 12

The exact location of the porcelain excavated in Table 1 is shown in Figure 1.

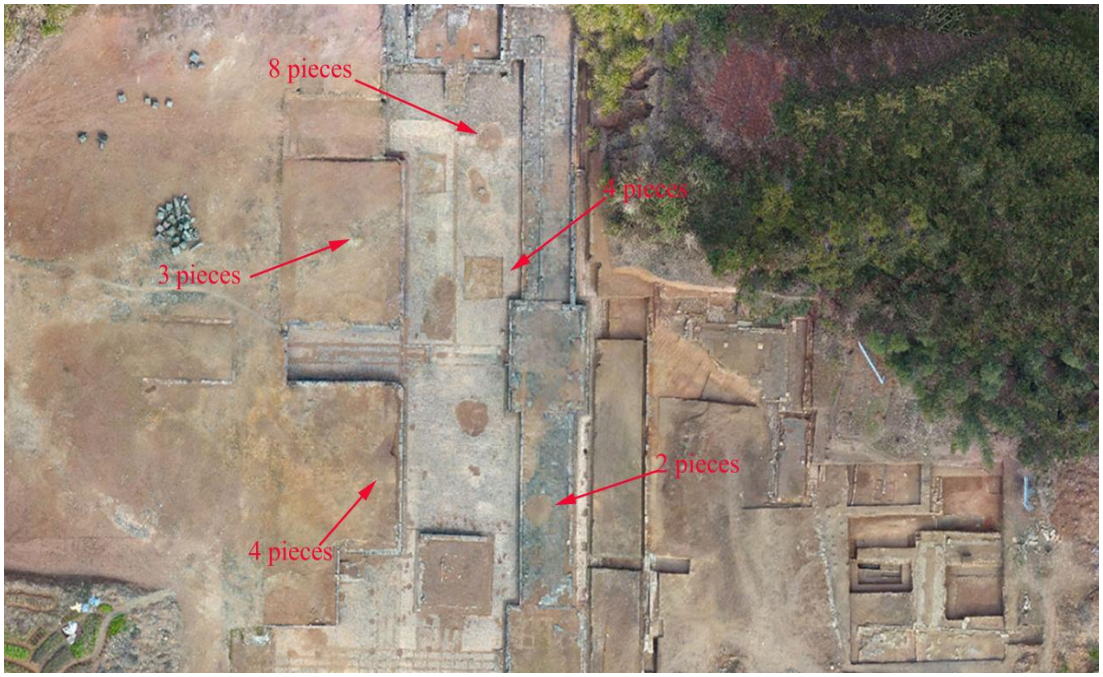

Figure 1. The Quantity and Location of Tsinghua Porcelain Excavated

Note: In the subsequent analysis, representative samples will be selected for analysis, so there is a problem of inconsistent time.

The blue and white porcelain from the ruins of the ancient city of the Qing Palace was numbered, and samples were tested with tweezers, magnifying glasses, plaster, sealed bags, metal colorimetric cards and other materials. Firstly, the blue and white porcelain was preliminarily screened with a magnifying glass, including the pattern, color, line, and bubbles of the enamel, and representative samples YL-1(a), YL-03(b), YL-05(c) and YL-11(d) were selected. It is then encapsulated in a sealed bag and inspected by an electron microscopy scanner to determine the metal spectrum. The sample was spliced with plaster, and the original appearance of the sample was restored as much as possible to obtain the sample's shape, and the splicing angle error was less than 3°. Record the width, height, weight, and other information of the model. Among them, a representative sample is shown in Figure 2.

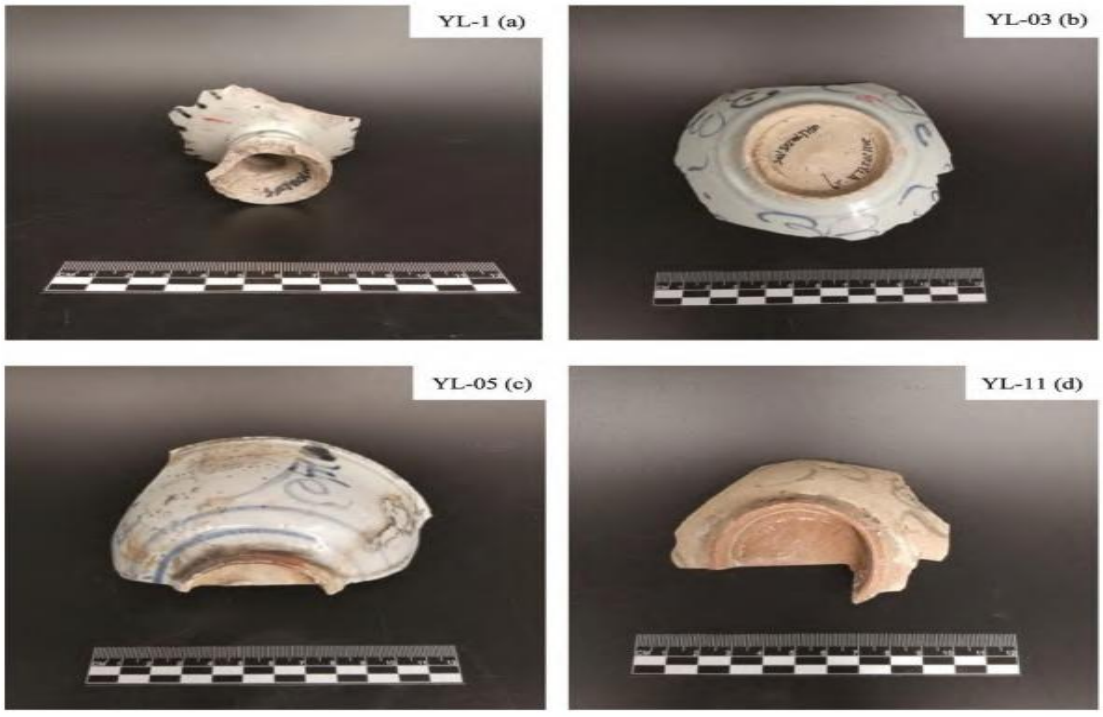

Figure 2. Blue and White Porcelain Samples Unearthed from the Remains of Qing Palace

Microstructure Analysis Results

Characteristics of Southern Quartz and Sericite Porcelain

Southern quartz and sericite porcelain are two crucial types of traditional Chinese porcelain and have some characteristics in microstructure. Here are some of their typical features:

Southern quartz porcelain: The presence of quartz crystals in the microstructure: There are usually a large number of quartz crystals in the glaze of southern quartz porcelain, which are characterized by a fine, uniform and natural arrangement (Pavlenko, Borysov, Sorokun, & Slobodian, 2021). Uniformity of microstructure: The microstructure of southern quartz porcelain usually shows relatively constant and dense characteristics. Combination of quartz crystal and glaze: Quartz crystal and glaze are closely bonded, forming a glaze with particular strength and hardness.

Sericite porcelain: The presence of sericite crystals in the microstructure: The microstructure of sericite porcelain is rich in sericite crystals, which are in an elongated form and arranged in order. Layered features of microstructure: The microstructure of sericite porcelain usually exhibits layered features due to the flake arrangement of sericite crystals. Combination of sericite crystals and glaze: Sericite crystals combine well with glaze to form a strong and tough glaze structure.

Association with Hutian Kiln in Jingdezhen

Jingdezhen Hutian kiln is a vital kiln mouth in traditional Chinese porcelain, famous for the production of blue and white porcelain. Southern quartz porcelain and sericite porcelain are related to the Jingdezhen Hutian kiln. The blue and white porcelain production process of Jingdezhen Hutian kiln often uses southern quartz porcelain and sericite porcelain as glaze materials. The uniform microstructure of southern quartz porcelain and the high hardness of quartz crystals can improve porcelain's durability and thermal shock resistance, making porcelain stronger. The layered microstructure of sericite porcelain and the toughness of sericite crystals can increase the toughness of porcelain and reduce the risk of cracking and chipping caused by temperature changes. The use of southern quartz porcelain and sericite porcelain in the Hutian kiln in Jingdezhen is closely related to the porcelain-making process and firing process, which provides essential physical property support for the production of blue and white porcelain. At the same time, the microstructural characteristics of southern quartz porcelain and sericite porcelain have also become an essential basis for identifying and studying Jingdezhen Hutian kiln porcelain.

Energy Dispersive X Fluorescence Spectroscopy Analysis Results

Analysis of Glaze Characteristics

The samples excavated in Table 1 were analyzed by electron microscopy, and through the study of the main components, it was found that 21 samples mainly contained chemical elements such as Na_2O, MgO, Al_2O_3, etc., and the proportion of each element changed, and the analysis results were shown in Table 2.

Table 2. Chemical Composition of Blue and White Porcelain (unit: %)

Sampling Number	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3	MnO	P_2O_5
1	1.51	0.60	19.26	75.19	3.87	0.32	0.15	1.22	1.44	0.03
2	0.67	0.85	21.61	79.03	4.36	0.32	0.49	1.35	2.11	0.03
3	0.61	1.22	21.52	72.33	4.45	0.39	0.02	0.34	1.27	0.03
4	1.01	0.25	26.17	75.95	4.28	0.34	0.37	0.32	1.48	0.04
5	0.96	1.06	28.82	78.25	3.53	0.56	0.34	1.16	1.71	0.02
6	0.50	0.74	27.22	74.33	3.93	0.24	0.42	0.52	2.34	0.01
7	1.09	1.40	27.16	71.45	5.38	0.39	0.07	1.35	1.74	0.06
8	0.66	1.31	29.25	75.66	4.66	0.40	0.48	0.81	1.35	0.03
9	1.21	1.36	23.98	78.15	4.81	0.29	0.41	1.31	2.11	0.03
10	0.52	1.11	23.79	78.68	3.48	0.29	0.40	0.92	2.01	0.01
11	0.82	1.21	25.95	79.51	4.13	0.42	0.17	0.24	1.97	0.02
12	0.80	1.07	20.64	74.85	4.59	0.27	0.45	0.98	2.40	0.02
13	1.45	0.93	23.69	76.09	4.27	0.55	0.06	1.25	1.98	0.04
14	1.48	1.38	26.19	73.55	4.33	0.45	0.47	0.71	1.91	0.04

Sampling Number	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3	MnO	P_2O_5
15	0.91	1.19	25.68	72.66	3.63	0.27	0.08	0.83	2.53	0.03
16	0.69	1.13	27.70	70.56	4.55	0.44	0.20	0.34	1.38	0.04
17	1.21	0.28	21.78	76.04	4.67	0.34	0.54	0.45	1.71	0.04
18	0.63	0.58	22.49	70.19	4.61	0.31	0.33	0.71	1.69	0.03
19	0.46	0.24	28.11	73.52	4.12	0.42	0.18	0.63	2.33	0.03
20	0.81	0.53	26.75	77.62	4.89	0.30	0.55	1.44	2.32	0.02
21	1.39	1.49	29.12	73.32	4.65	0.35	0.47	0.69	1.91	0.01

The chemical composition of blue and white porcelain in Table 2 shows that the content of Al_2O_3 and SiO_2 in the porcelain glaze fluctuates little. Among them is Al_2O_3. The content was between 18.83 wt.%~23.95 wt.%, the SiO_2 content was between 68.34 wt.%~74.45 wt.%, the Fe_2O_3 content fluctuated greatly, between 1.12 wt.%~2.30 wt.%, and the TiO2 content was low, between 0.05 wt.%~0.22 wt.%. Combined with the chemical composition of porcelain stone, it can be seen that the Al_2O_3 content in blue and white porcelain glazes is higher than that in porcelain stone, indicating that the raw materials were washed or added to kaolin during glaze making to improve the porcelain glaze the content of Al_2O_3. In the early days of Jingdezhen porcelain, only a single porcelain stone was used as a raw material, and a single porcelain stone was used as a raw material for glaze making, which was difficult to make the Al_2O_3 content in the porcelain glaze exceeded 20 wt.%.

The content of Al_2O_3 in blue and white porcelain glazes is higher than that of porcelain Al_2O_3. Considering that ancient porcelain is generally taken from local materials, it can be seen that when making blue and white glazes, kaolin with higher aluminum content is used to increase the content of Al_2O_3 in porcelain glazes (Pourcelot, 2022). The increase of Al_2O_3 content in porcelain glazes can reduce the deformation rate of the green body during the firing process, broaden the firing temperature range of porcelain, improve the density and glaze quality of porcelain glazes, generate more mullite crystals, improve flexural strength, and improve the quality of porcelain. The color of porcelain glazes is greatly affected by the coloring oxides Fe_2O_3 and TiO_2.

In contrast, the Fe_2O_3 content in blue and white porcelain glazes is higher, and Fe_2O_3 will form dark brown spinel with TiO_2 at high temperatures, producing coloring and reducing the transmittance and whiteness of porcelain. The Fe_2O_3 content in Jingdezhen official kiln porcelain glazes is generally 0.50 wt.%~1.00 wt.% (Rasmussen et al., 2022), while the Fe_2O_3 content in blue and white porcelain glazes is significantly higher, both exceeding 1.00 wt.% so that the transmittance and whiteness of the glazes are greatly affected. The overall overview of the chemical elements of the sample in Table 1 is shown in Figure 3.

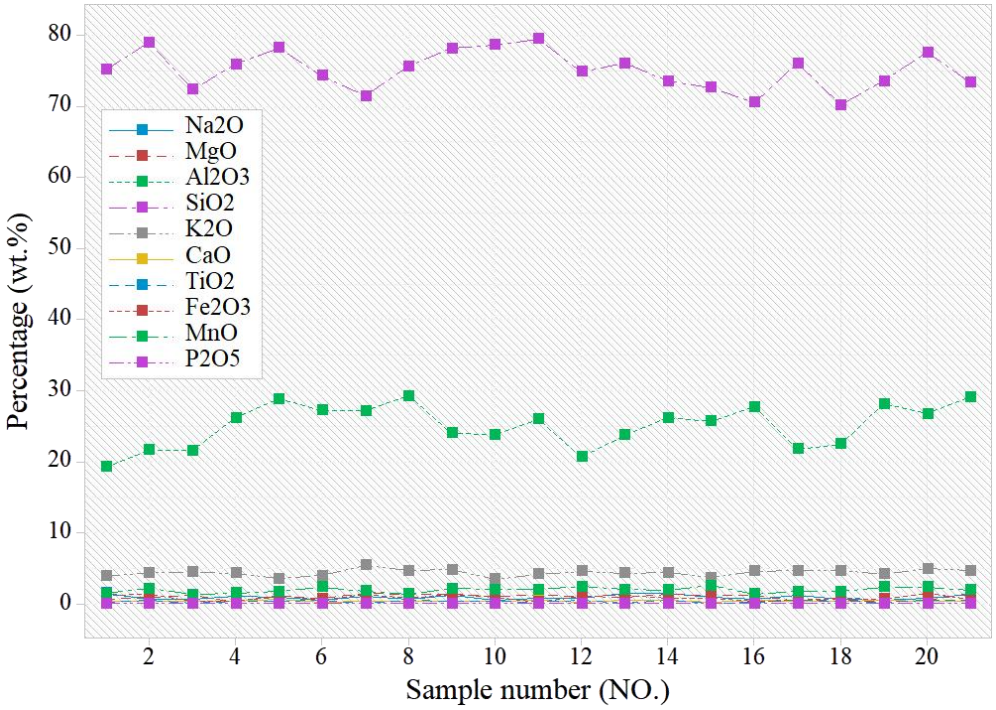

Figure 3. The Chemical Element Content of the Sample

Note: The X-axis represents the sample number, which is 1~21; The ordinate represents the content of elements such as Na_2O, MgO, Al_2O_3, etc.

As shown in the line chart of Figure 2, the MnO content is between 0.03 wt.%~0.50 wt.%, and the P_2O_5 content is between 0.02 wt.%~0.09 wt.%. In general, the chemical composition of blue and white porcelain glazes has a wide distribution range, which is consistent with its glaze color difference characteristics. According to the EDXRF analysis results, the sample showed "high silicon and low aluminum", indicating that the silicon content in the sample's glaze composition was relatively high, while the aluminum content was relatively low. This could mean using a higher proportion of silicate minerals such as kaolin as the main component in the glaze while reducing the use of aluminum-rich minerals such as bauxite. This glaze formulation may be characterized by acquiring specific porcelain properties, such as increased thermal shock resistance, improved texture hardness, etc. (Vyhnal, 2022).

Application of Unilateral Formulation Process

The unilateral formulation process refers to using only one mineral as the glaze material in porcelain production, and no other minerals are mixed. EDXRF analysis can help determine whether a sample uses a unilateral formulation process. If the analysis results show that only one major element in the selection is significantly higher than the others, it can be preliminarily assumed that the model used a unilateral formulation process. Applying the unilateral formulation process can make the production process simpler and more precisely controlled, which is conducive to improving product consistency and quality stability. However, unilateral recipes may also limit the diversity of styles and decorations of porcelain, so trade-offs and choices must be made according to needs and requirements in the actual production process.

Analysis of the Appearance Characteristics and Whiteness Value of Glaze

Typical Southern Blue-and-White Porcelain Features

Southern blue and white porcelain is one of the important types of traditional Chinese porcelain with a unique decorative style and appearance. Typical southern blue and white porcelain characteristics include: the glaze is transparent and shiny, showing a glazed luster effect; the blue and white painting method is delicate and smooth, and the lines are soft, depicting natural scenes, flowers, birds, figures and other patterns; the decorative elements are mostly natural patterns such as cloud heads, clouds, and waves, which have the unique style of Jiangnan water town; the overall texture of the glaze is hard and delicate, and the glaze surface is smooth (Yang, 2021).

Meaning and Inference of Whiteness Values

The whiteness value is a common indicator of the whiteness of porcelain glaze. By measuring the reflectivity of the porcelain glaze, the higher the calculated value, the higher the whiteness of the glaze. Analysis of whiteness values can reveal the quality and appearance characteristics of the sample glaze. A higher whiteness value usually means that the glaze is whiter in color and appears purer white. In blue and white porcelain, the whiteness value of the glaze can affect the rendering and contrast of the blue and white pattern. A higher whiteness value can enhance the clarity and vividness of the blue and white painting and make the ornamentation more vivid. By analyzing the glaze whiteness value, the quality and decorative effect of the sample can be further inferred. For example, if the sample has a high whiteness value, it may indicate that the glaze firing quality is good and the formulation and firing process of the glaze are effectively controlled. A lower whiteness value may mean the glaze has quality problems, such as uneven glaze, defects, or an unsatisfactory formulation (Yilmaz, Özkul Findik, & Aytekin, 2022).

COMPONENT ANALYSIS COMPARISON AND RESULT DISCUSSION

Introduction to the PCA Method

Principal Component Analysis is a commonly used statistical analysis method to reduce dimensions and extract the main features in a dataset (Omar, 2022). By transforming high-dimensional datasets into low-dimensional spaces, PCA can help us discover our data's main patterns and structures. The basic principle of PCA is to look for principal components in the data, which are the projection direction of the original data in the feature space (Madrid i Fernández, Peix Visiedo, & Buxeda i Garrigós, 2021). The principal component represents the maximum variance in the data, so retaining the main detail preserves the total amount of information in the dataset. These principal components are independent variables in the data, and the original data can be represented with fewer main components, thereby achieving dimensionality reduction of the data (Metaxia et al.,

2022).

Mathematical Description of the Composition of the Glaze

PCA analysis can effectively perform PCA to make reasonable decisions and detect the changing characteristics of glaze data. The principal component analysis mainly calculated the peak value of glaze based on the glaze index. Principal component analysis uses the glaze theory to perform computer-aided analysis of the glaze data to complete the comprehensive identification (Christopoulou, Laskaris, & Ganetsos, 2020). Among them, the peak change direction of the glaze constituent elements represents the value of interest. The principal component analysis needs to be defined in two ways: as follows.

Glaze data collection: Any glaze data is h_i, the comparison function of glaze composition is $q(y_i)$, the set of glaze is x_i, and the length of time is t_i. Then, the $q(y_i)$ calculation process is shown in Equation (1).

$$q(y_i) = t_i \times h_i \cdot x_i \tag{1}$$

Judgment of glaze composition: The accuracy function of glaze is that it is the accuracy of the constituent elements p, the accuracy $k(x)$ of the constituent elements b_v of the glaze (Burbidge, Rodrigues, Dias, Prudêncio, & Cardoso, 2010), and the accuracy b_s of the composition of the glaze. Well, the $k(x)$ calculation process is shown in Equation (2).

$$k(x \cdot P) = x \xrightarrow{y} \sqrt{b_s \cup b_v} \tag{2}$$

Comparison of glaze composition results: The function of the recognition result of the glaze composition, the composition element changes to $s(x_i)$ (Ali, Darwish, & El Sheikha, 2020), the set of constituent elements is $\bar{x}_i$, and the number of constituent elements is col_i. Well, the $s(x_i)$ calculation process is shown in Equation (3).

$$s(x_i) = \sum col_i \div h_i \cdot x_i \tag{3}$$

Summary of glaze composition characteristics: The function of glaze composition elements is $k(x,b)$, the characteristic value of the glaze component elements is $k(x)$ and the error of the glaze is w, composition elements is ξ. Well, the calculation process is shown in Equation (4).

$$k(x) = \sum_{i=1} x_i \times w \div \zeta_i \tag{4}$$

Comparison Results of Glaze Composition

In the PCA process, the glaze composition data should be comprehensively calculated to reduce the error rate of the glaze. According to the theory of glaze, it is necessary to identify the different chemical composition and structural composition elements. Therefore, it is required to conduct a random analysis of varying chemical composition elements, structural composition elements and comprehensive composition elements of other glaze elements (Zacharias, Palamara, Kordali, & Muros, 2020).

Chemical composition comparison: The judgment function of chemical elements is $k(x_i \cdot J_i)$ that when the characteristic value appears, $h(x_i \cdot y_i) \in [0,1]$ the composition element is reasonable. $k(x_i \cdot J_i)$ The calculation is shown in Equation (5).

$$k(x_i) = \frac{h(x_i^2) \cdot (1 - P_i)}{Ya \cdot \sqrt{1 - k^2}} \cdot \lim_{x \to \infty} \tag{5}$$

Formula: If the $F(x_i) \le 1$ analysis results of the glaze composition are reasonable, the content of the glaze and the elements of the glaze composition should be analyzed. If $F(x_i) \ge 1$ is stated that the results of the analysis of the glaze composition do not meet the requirements of the glaze, the glaze composition should be adjusted, as shown in Figure 4.

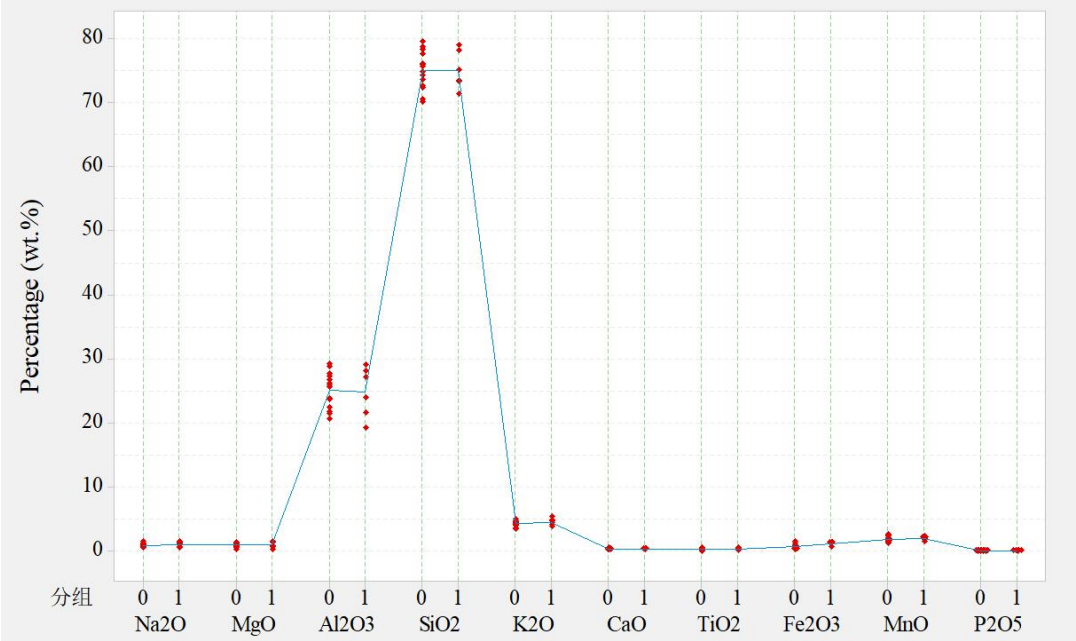

Figure 4. Comparison of the Composition of Qinggong Ancient City Ruins and Southern Blue and White Porcelain

Note: 1 represents Qing Palace ancient city ruins blue and white porcelain, 0 represents Hutian and Fanchang kiln blue and white porcelain.

It can be seen from Figure 4 that in terms of chemical composition, the glaze composition of blue and white porcelain at the ancient city site of the Qing Palace is not much different from that of southern blue and white porcelain, and the median connection is relatively straight, indicating that the glaze composition of blue and white porcelain at the ancient city site of the Qing Palace is influenced by southern blue and white porcelain. Among them, the design of AL_2O_3 (Sadek, 2016), MnO, and K_2O is different, mainly due to the difference between the soil extraction, firing temperature and humidity of blue and white porcelain from the ancient city site of the Qing Palace. The components' common characteristics and possible production processes can be revealed by analyzing the common composition of the samples of the ancient city of Qing Palace and the southern blue and white porcelain. The significance of the standard composition is to reveal the production process: if the samples of the ancient city of Qing Palace have similar standard components with southern blue and white porcelain, it may indicate that they use similar glazes and minerals, adopt identical production processes, have similar firing temperatures or firing environments, etc., reflecting geographical characteristics: the existence of standard components may also reflect the typical characteristics of the geographical location where the samples are located, such as the relative richness of mineral resources in the same area or the particular geological environment. Through the comparative analysis of the standard components, combined with historical documents and other archaeological data, it can be speculated that the standard components of the samples of the ancient city of Qinggong and southern blue and white porcelain may include glaze material components, such as kaolin, clay, etc.; Glaze components: such as iron-containing glazes; Blue and white drawing elements: such as the cobalt composition used.

Comparison of structural composition: The crystal structure judgment function of glaze is $k(o)$ calculated as shown in Equation (6).

$$k(o) = y(x_i \cdot y_i) \cdot e_i \cdot f(x_i) \tag{6}$$

The analysis results are shown in Figure 5.

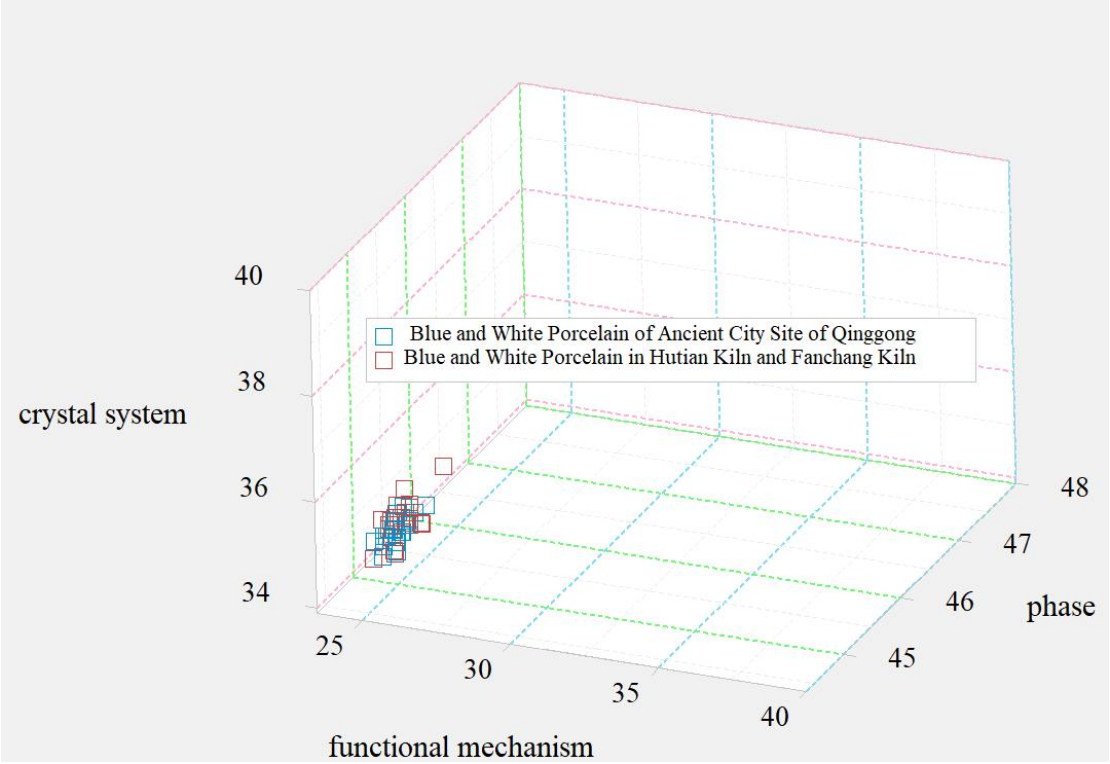

Figure 5. Comparison of Structural Composition

It can be seen from Figure 5 that there is no significant difference between the Qing Palace ancient city site and the Hutian kiln and Fanchang kiln blue and white porcelain in terms of crystal system, phase and functional mechanism, which further indicates that the blue and white porcelain in the ancient city site of the Qing Palace was significantly influenced by southern blue and white porcelain. It can be speculated that this batch of blue and white porcelain samples should have been produced by the Hutian kiln in Jingdezhen in the Song Dynasty, used by the middle and upper-class rulers of Kaifeng, Jingdezhen, and then circulated to the Central Plains through trade.

It can be seen from Figure 5 that although there are 0~5% differences in crystal system, phase and functional mechanism between the ancient city site of Qinggong and the blue and white porcelain of Hutian Kiln and Fanchang Kiln, the porcelain in the ancient city site of Qinggong has been buried underground for about 50~80 years, and will undergo organic changes to a certain extent under the action of temperature, humidity and oxidation. Therefore, the error of 5% is in an acceptable range, and it is preliminarily determined that the sample blue-and-white porcelain is basically similar to the southern blue-and-white porcelain. It can be speculated that these blue and white porcelain samples should be tributes produced by Hutian Kiln and Jingdezhen Kiln in Jingdezhen in Song Dynasty.

Comparison with Other Compositions of Hutian Kiln and Fanchang Kiln

Hutian kiln and Fanchang kiln are two important kiln mouths in the Jingdezhen area of Jiangxi Province, China, and play an essential role in producing blue and white porcelain in the south. Although both kilns have blue and white porcelain, specific differences exist in their production process, decorative style, and porcelain characteristics. Therefore, the particular analysis of the coincidence of Hutian kiln and Fanchang kiln samples needs to consider the following aspects:

Production process: There are slight differences between the Hutian and Fanchang kiln production processes. Hutian kilns are usually made of uniform and fine kaolin. The kiln temperature is high, the fired porcelain is hard in texture, and the glaze is generally smooth. The Fanchang kiln, on the other hand, uses a mixture of clay and kaolin as the glaze material. The kiln temperature is low, the texture of the fired porcelain is relatively soft, and the glaze often has a certain roughness. Regarding the production process, there may be specific differences between the samples of the Hutian kiln and the Fanchang kiln.

Decoration style: The decorative styles of Hutian and Fanchang kiln are also different. The blue and white porcelain of the Hutian kiln is often characterized by smooth blue brushstrokes and free texture, and common decorative patterns include cloud heads, clouds, and waves. The blue and white porcelain of Fanchang Kiln pays more attention to the delicate hook line, the light and heavy line change, and the typical decorations are Ruyi cloud head, lotus flower, flower, etc. Therefore, regarding decorative style, the overlap of Hutian and Fanchang kiln samples may differ.

Porcelain characteristics: In addition to the production process and decorative style, the porcelain characteristics of the Hutian and Fanchang kiln samples are also worth comparing. For example, by observing and testing the quality and glaze, it is possible to compare the characteristics such as texture, transparency and gloss of the sample. In addition, the sample's size and shape can be compared. A comparison of these porcelain features can reveal similarities and differences between the samples of the Hutian kiln and the Fanchang kiln.

Differences Between the Ancient City Ruins of the Qing Palace and Other Kiln Mouth Samples

Hutian kiln and Fanchang kiln are two kilns with important historical positions in the Jingdezhen area of Jiangxi Province, and they have unique characteristics in the production of southern blue and white porcelain. Here are a few aspects of the differences between the Hutian kiln and Fanchang kiln samples from other kiln mouth samples.

Differences in the production process: Hutian kiln and Fanchang kiln may have differences in production technology and other kiln mouths. Each kiln mouth has its unique craft tradition and technical characteristics, such as the formula of glaze, the preparation method of glaze material, decorative techniques, etc. These differences can lead to significant texture and cosmetic effect differences between kiln mouth samples.

Differences in decorative styles: Blue and white porcelain at different kiln mouths often have differences in decorative styles. Free and smooth brushstrokes and textures often characterize the blue and white porcelain decoration of the Hutian kiln and Fanchang kiln, and the patterns are mostly cloud heads, cloud mist, waves, etc. Other kiln mouths, such as Yixing kiln and Dehua kiln, may have different decorative features and patterns, such as flowers and birds, figures, landscapes, etc., as themes.

Differences in the use of mineral materials: There are also differences in the selection and use of mineral materials at different kiln mouths. Hutian kilns and Fanchang kilns mostly use cobalt for blue and white painting, a typical decorative material for blue and white porcelain in the south. Other kiln openings may be decorated with different materials or specific minerals.

Differences in porcelain characteristics: The samples of the Hutian kiln and Fanchang kiln may differ from samples from other kilns. This includes aspects such as the glaze's texture, the glaze's quality and color, and the glaze's shape and shape. These feature differences can be evaluated and identified using microstructure observation, glaze analysis, and object comparison.

There may be specific differences between the samples of the Hutian kiln and Fanchang kiln and samples from other kiln mouths regarding the production process, decorative style, use of mineral materials and porcelain characteristics. By comparing and analyzing these differences, the features and styles of different kiln mouth samples can be better understood and identified.

THE REASON FOR THE DIFFERENCE IN THE COMPOSITION OF THE GLAZE OF CHINESE BLUE AND WHITE PORCELAIN POTS

Different Sources and Production Times

For specific blue and white porcelain samples, determining their possible sources and production time requires careful consideration of multiple factors, such as the sample's characteristics, decorative style, vessel type, location and archaeological background. By analyzing the features and decorative style of the piece, it was possible to compare it with the known blue and white porcelain kiln mouth to determine the possible production location. Considering the long history of blue and white porcelain production, blue and white porcelain production may exist in different periods and regions. Therefore, combined with the historical background of the sample, such as the rise and fall of ancient dynasties, political and economic changes, etc., the production time of the model can be preliminarily inferred.

Different Circulation Ranges

Hutian kiln is a vital kiln mouth in the Jingdezhen area of Jiangxi Province, famous for producing blue and white porcelain. Hutian kiln blue and white porcelain has an essential position in the Chinese and even international blue and white porcelain market because of its exquisite production technology and unique decorative style. The circulation of Hutian kiln blue and white porcelain is mainly concentrated in China, especially in the society of the Ming dynasties (AD 1654~1885). The circulation channels of blue and white porcelain may include palaces, official palaces, temples, local nobles, merchants, etc., which may enter social circulation through tribute, gifts, trade, etc., and are used for daily life, decoration and gift exchange.

Different Circulation Routes

Through studying ancient historical documents, overseas cultural relics, excavations and archaeological findings, which can preliminarily speculate the blue and white porcelain circulation routes. Ancient documents

record the circulation of some blue and white porcelain, such as books such as "A Thousand Miles of Jiangling Sunrise" and "Eunuch Shizhan Gold and Silver Branch" in the Ming Dynasty (AD 1369~1472), which can provide some clues. In addition, some blue and white porcelain excavated overseas also indicates the international circulation of blue and white porcelain. According to historical documents and archaeological findings, blue and white porcelain may have circulated to Southeast Asia, South Asia, the Middle East, Europe and other places through the Silk Road, the Maritime Silk Road, and different trade routes. Among them, the Maritime Silk Road influenced the overseas spread of blue and white porcelain. Blue and white porcelain passed through multiple transit points along long trade routes, perhaps through merchant ships, trade bazaars or go-betweens. Comprehensively considering ancient documents, archaeological discoveries and historical background, combined with the characteristics and causes of blue and white porcelain samples, it is possible to speculate on their possible circulation routes and influence ranges. However, due to the complexity of history and the incompleteness of the information, the speculation still needs further research and confirmation.

RESEARCH THE SIGNIFICANCE OF CHINESE BLUE AND WHITE PORCELAIN POT GLAZE COMPOSITION

Understanding and Supplementing the Chinese Blue and White Porcelain Porcelain Craft

By studying blue and white porcelain samples, we can deeply understand the technical characteristics, decorative style and evolution of Chinese blue and white porcelain porcelain making process. As an essential representative of traditional Chinese porcelain, blue and white porcelain has always attracted much attention for its production technology and decoration techniques. Through the study of samples, the understanding of blue and white porcelain can be supplemented and expanded, and the differences in the production process and decorative style of blue and white porcelain in different kiln mouths and different historical periods can be revealed.

Understanding and Expansion of the Trade and Circulation of Porcelain

By studying blue and white porcelain samples, the understanding of the trade circulation of ancient porcelain can be enhanced. As a representative of traditional Chinese porcelain, blue and white porcelain has extensive trade influence. Studying the origin, circulation routes and circulation scope of blue and white porcelain samples can explore important issues such as the formation of ancient trade networks, the role of porcelain in trade, and cultural exchanges between different regions.

Excavation and Value of the History and Culture of the Ancient City Site of Luohe

Studying the blue and white porcelain samples from the ruins of the ancient city of Luohe can not only gain an in-depth understanding of the local and regional culture but also provide important clues to the evolution and inheritance of Chinese history and culture. The study of samples reveals the historical background, social and cultural characteristics, and economic and trade information of the ancient city site of Luohe. This will help promote the comprehensive excavation of ancient city sites, protect and inherit history and culture, and increase its value in cultural tourism and education.

Insufficient Research in this Paper

Future research can further expand the scope and depth of investigation of blue and white porcelain samples, focusing on the production process and decorative style of blue and white porcelain and combining new scientific and technological means for more comprehensive and detailed research. For example, samples can be analyzed using non-destructive testing methods such as scanning electron microscopy, elemental analysis, isotope analysis, etc., to obtain more information on composition and manufacturing characteristics. In addition, it can also be combined with digital technology to establish a database of blue and white porcelain samples to achieve information sharing and comparative research. Continuous in-depth analysis can further enrich the understanding of Chinese blue and white porcelain and related cultures and promote the protection and inheritance of traditional Chinese porcelain culture.

CONCLUSION

As an important archaeological site, a small amount of blue and white porcelain was unearthed. In this paper, 21 representative pieces were identified from the excavated blue and white porcelain, and electron microscopy scanning and spectrometer measurements were carried out to record the relevant data. The study found that 21 pieces of blue and white porcelain contained Na_2O, MgO, Al_2O_3 and other main chemical components, and the chemical composition showed specific differences. The 21 samples are similar to the blue and white porcelain of

Hutian and Fanchang Kiln (AD 1018~1032) in the Song Dynasty, indicating that the excavated samples are Song Dynasty blue and white porcelain. In addition, the main chemical composition analysis of 21 samples showed that the aluminum and silicon content in the instances gradually increased, indicating that the blue and white porcelain production process of Hutian and Fanchang kilns (AD 1028~1032) in the Song Dynasty changed, which was the same as that in the early Qing Dynasty (AD 1042~1052). Therefore, the 21 pieces of blue and white porcelain unearthed at the site of the Great Shangqing Palace of Longhu Mountain provide a witness to the Taoist status and development milestone of the Great Shangqing Palace of Longhu Mountain.

AUTHOR CONTRIBUTIONS

All the author's contributions are equally in the manuscript.

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