

An Archaeometric Study of Longquanwu Kiln White Porcelain Excavated from the Jin Zhongdu Site

Shuang Wang

College of Applied Arts and Sciences, Beijing Union University, Beijing 100101, China

Abstract: This study aims to clarify the technological characteristics, kiln attribution, and circulation of Liao–Jin white porcelain recovered from urban archaeological sites in Beijing. Twenty-two white porcelain sherds from Liao–Jin stratigraphic contexts at the Caiyuan Street Site of Jin Zhongdu, Beijing, were examined using water-absorption testing and micro-X-ray fluorescence (μ -XRF) analysis to characterize body densification and the chemical compositions of the ceramic bodies and glazes. The results indicate that the bodies were highly sintered and dense, with generally low water absorption ranging from 0.02% to 0.99%. The bodies exhibit the high- Al_2O_3 /low- SiO_2 compositional signature typical of northern Chinese white porcelain and contain relatively high levels of the fluxes Na_2O and K_2O , suggesting the use of a kaolin–feldspar raw-material formulation. The glazes show considerable compositional diversity, including calcium, calcium–alkali, and alkali–calcium types; the occurrence of alkali–calcium glazes is interpreted as evidence of advances in glaze technology. Comparison with white porcelain excavated from the Longquanwu kiln site and with Ding kiln white porcelain of the Song–Jin period indicates that the Caiyuan Street assemblage was likely produced at the Longquanwu kiln. Its bodies are characterized by high Na_2O – K_2O , low MgO – CaO , high TiO_2 , and low Fe_2O_3 contents, whereas the glazes are characterized by low Al_2O_3 and high Na_2O – K_2O contents. These results provide scientific evidence for the technological characteristics and provenance of Longquanwu kiln white porcelain and contribute to research on the urban archaeology of Jin Zhongdu and Liao-period ceramic trade.

Keywords: Longquanwu kiln white porcelain, archaeometry, Jin Zhongdu site, Liao–Jin period, body and glaze composition.

1. Introduction

The Caiyuan Street Site of Jin Zhongdu is located in Xicheng District, Beijing, north of Baizhifang West Street, south of Zaolin Front Street, west of You'anmen Inner Street, and east of Caiyuan Street. The terrain is generally level. To accommodate construction on Plot E of the Caiyuan Street and Zaolin Nanli shantytown redevelopment project in Xicheng District while protecting subsurface cultural heritage, the Beijing Municipal Institute of Cultural Relics organized a rescue excavation of identified archaeological remains in the project area from 20 July to 20 September 2019. Beijing Union University collaborated in the excavation. Features including river channels, roads, wells, hearths, and ash pits were exposed, and a large quantity of ceramics was recovered, including glazed earthenware, white porcelain, celadon, blue-and-white porcelain, and brown-glazed porcelain. Six stratigraphic layers were identified. Layer 1 was a modern disturbed deposit containing substantial domestic and construction debris. Layer 2 dated to the Ming and Qing dynasties and yielded mainly white porcelain and blue-and-white porcelain. Layers 3 and 4 were Liao–Jin cultural deposits dominated by white porcelain, with smaller quantities of brown-glazed porcelain and celadon. Layer 5 was a Liao-period deposit, dominated by white porcelain with a smaller quantity of celadon; this layer was absent in the eastern part of the excavation area. Layer 6 was a Tang-period deposit, also dominated by white porcelain with a smaller quantity of celadon. Yellowish-brown sterile soil lay beneath Layer 6.

The Longquanwu kiln is located in Longquanwu Village, Mentougou District, Beijing, west of the Yongding River. It was first identified during Beijing's first municipal cultural-relics survey in 1958–1959 and was subsequently investigated on several occasions. Joint archaeological teams

from the Beijing Municipal Institute of Cultural Relics and the Mentougou District Cultural Relics Administration carried out two excavation campaigns, in 1991–1994 and in 2005. The kiln was established in the early Liao dynasty, reached its peak in the late Liao period, and continued operating into the early Jin dynasty. Its production history can be divided into four principal stages. In the early Liao period, white porcelain predominated and the glaze colors resembled those of the Ding kiln in the Northern Song dynasty. During the middle Liao period, production diversified to include sancai wares, glazed architectural ceramics, Buddhist images, and other products, accompanied by substantial technological improvement. In the late Liao period, the product range expanded further to include brown-glazed porcelain and sancai wares, with brighter and more vivid glazes. In the early Jin period, black-glazed ceramics became dominant, although white porcelain and sancai wares continued to be produced.

Large quantities of white porcelain were excavated at the Caiyuan Street Site. On the basis of conventional archaeological typology, many examples had been attributed to kilns such as Ding and Xing. Whether some of these wares represented locally produced and locally circulated Longquanwu kiln white porcelain could not be confirmed because scientific evidence was lacking. The white porcelain from Liao–Jin Layers 3 and 4 has hard, dense bodies and slightly yellowish-white glazes. Most plates and bowls preserve three to five spur marks on the inner floor or outer foot. These kiln-setting features are consistent with excavated Longquanwu kiln products and therefore provide an initial technological basis for attribution, but scientific analysis is required for verification. Moreover, Longquanwu and Ding white porcelains were produced using similar techniques, and Longquanwu imitated Ding white porcelain during certain periods [1]. Visual assessment alone is therefore insufficient to distinguish white porcelains from different kiln centers.

Scientific analytical methods are therefore required to systematically characterize the physical properties and chemical compositions of the ceramic bodies and glazes and to compare them with reference data from known kiln sites. Such comparisons can establish objective criteria for kiln attribution and provide a reliable basis for determining whether the white porcelain excavated at Jin Zhongdu was locally produced at the Longquanwu kiln.

As analytical techniques have advanced, scientific methods have increasingly addressed questions that are difficult to resolve through conventional archaeology alone. For Longquanwu white porcelain, such methods can elucidate raw-material processing, body and glaze formulations, physical properties, firing technology, firing temperature, and coloration mechanisms. Comparative analysis with white porcelains from other kiln sites can also identify distinctive geochemical fingerprints. To date, archaeometric research on Longquanwu white porcelain has been limited to studies by Chen Yaocheng and colleagues [2,3], Cheng Lin and colleagues [4], Fang Tao and colleagues [5], and a small number of other researchers. A comprehensive and systematic scientific study of Longquanwu white porcelain recovered from Liao-period urban archaeological contexts therefore remains necessary.

This study examines 22 white porcelain samples recovered in 2019 by the Beijing Municipal Institute of Cultural Relics from Liao–Jin Layers 3 and 4 at the Caiyuan Street Site of Jin Zhongdu. These samples are considered probable Longquanwu kiln products and are hereafter referred to as the white porcelain samples. Their morphology, body and glaze compositions, and other key parameters are systematically analyzed to reconstruct technological practices at the

Longquanwu kiln and to consider the cultural relationship between Longquanwu and Jin Zhongdu..

2. Samples

Twenty-two white porcelain samples excavated at the Caiyuan Street Site of Jin Zhongdu were selected for analysis, comprising 10 bowls, one plate, one jar, and 10 sherds of unidentified vessel form (Fig. 1; Table 1). The samples were numbered CYJLQWY1–22. Their bodies are generally hard and dense, and the white glazes have a slight yellowish tint. Most plates and bowls preserve three to five spur marks on the inner floor or foot. Body thickness varies, and pores, small particles, and black speckled inclusions are present in some specimens. The body and glaze of each sample were analyzed separately.



Fig. 1 Selected white porcelain samples analyzed in this study.

Table 1. Macroscopic characteristics of the white porcelain excavated from the Caiyuan Street Site, Jin Zhongdu.

No.	Sample ID	Macroscopic description
1	CYJLQWY-1	Bowl sherd; thick, pure-white, dense body with a few black specks; thin, glossy glaze extending to the base, white with a yellowish tint; three surviving large elongated spur marks on the interior floor, originally forming a square arrangement; jade-ring base; low, thick ring foot with a steep inner bevel and spur marks.
2	CYJLQWY-2	Bowl sherd; thin, pure-white body with a few pores and black specks; thin, glossy glaze stopping short of the base, white with a yellowish tint; four intact small elongated spur marks on the interior floor in a square arrangement; jade-ring base; low, thin ring foot with clear spur-firing marks.
3	CYJLQWY-3	Bowl sherd; thick, grayish-white body with a few pores and numerous black specks; thin, glossy interior glaze, white with a yellowish tint; four intact large elongated spur marks on the interior floor in a square arrangement; jade-ring base; low, thick ring foot with an additional low, narrow inner ring and spur marks.
4	CYJLQWY-4	Bowl sherd; thin, pure-white body with very few pores and virtually no inclusions; thin, glossy interior glaze, white with a yellowish tint; three surviving large elongated spur marks on the interior floor, originally forming a square arrangement; jade-ring base; low ring foot with a moderately steep inner bevel and spur-firing marks.
5	CYJLQWY-5	Bowl sherd; relatively thin, pure-white, dense body with virtually no inclusions; thin, glossy glaze extending to the base, white with a yellowish tint; two surviving large elongated spur marks on the interior floor; jade-ring base; low, thick ring foot with spur-firing marks.
6	CYJLQWY-6	Bowl sherd; relatively thick, fairly white body with a few micropores and virtually no inclusions; thin, glossy interior glaze, white with a yellowish tint; two surviving large elongated spur marks on the interior floor; exterior covered by a thin transparent glossy glaze stopping short of the base; jade-ring base; low ring foot with spur marks.
7	CYJLQWY-7	Sherd of unidentified vessel form; relatively thick, grayish-white body with a few pores and inclusions; fully glazed interior and exterior glaze stopping short of the base; thin, glossy glaze, white with a yellowish tint; two incomplete spur marks on the interior floor; jade-ring base; low, thick ring foot with a steep inner bevel and spur marks.
8	CYJLQWY-8	Bowl sherd; relatively thin body showing a white central layer flanked by grayish-white layers; dense fabric with very few pores and virtually no inclusions; thin, glossy glaze extending to the base, white with a yellowish tint; two surviving large elongated spur marks on the interior floor; jade-ring base; low ring foot with a steep inner bevel and spur marks.
9	CYJLQWY-9	Bowl rim-and-body sherd; relatively thin, fairly white body with a few pores and inclusions; thin, glossy glaze stopping short of the base, white with a yellowish tint.
10	CYJLQWY-10	Jar rim-and-body sherd; thin, pure-white, dense body with virtually no inclusions; thin, glossy glaze on both interior and exterior, white with a yellowish tint; flared rim with annular decoration on the exterior.
11	CYJLQWY-11	Base sherd of unidentified vessel form; bulging body and flat base, with five concentric incised lines on the interior floor; relatively thin, pure-white body with a few pores and inclusions; thin, glossy glaze extending to the base, white with a yellowish tint.
12	CYJLQWY-12	Rim sherd of unidentified vessel form; relatively thin, pure-white body with a few pores and inclusions; thin, glossy glaze stopping short of the base, white with a yellowish tint.
13	CYJLQWY-13	Rim sherd of unidentified vessel form; relatively thin, pure-white, dense body with a few small black specks; thin, glossy glaze, white with a yellowish tint.
14	CYJLQWY-14	Rim sherd of unidentified vessel form; thin, pure-white body with a few pores and inclusions; thin, glossy glaze, white with a yellowish tint.
15	CYJLQWY-15	Rim sherd of unidentified vessel form; relatively thin, grayish-white body with a few pores and numerous small black specks; thin, glossy glaze, white with a yellowish tint.
16	CYJLQWY-16	Rim sherd of unidentified vessel form; thin, pure-white body with a few pores and a small number of black specks; thin, glossy glaze, white with a yellowish tint; numerous annular marks on the interior and exterior, with a raised feature on the exterior.
17	CYJLQWY-17	Base sherd of unidentified vessel form; thick, pure-white, dense body with virtually no inclusions; thin, glossy glaze on both interior and exterior, white with a yellowish tint; one surviving large elongated spur mark on the interior floor; jade-ring base; tall, thick ring foot with a steep inner bevel and spur-firing marks.
18	CYJLQWY-18	Bowl sherd; relatively thick, fairly white, coarse body with a few inclusions; thin, glossy interior glaze, white with a yellowish tint; two surviving large elongated spur marks on the interior floor, resembling a fish-shaped arrangement; jade-ring base; low ring foot with an additional low, narrow inner ring and spur marks.
19	CYJLQWY-19	Plate sherd; relatively thin, grayish-white, dense body with virtually no inclusions; thin, glossy glaze extending to the base, white with a yellowish tint; four intact large elongated spur marks on the interior floor in a square arrangement; jade-ring base; low, thin ring foot with spur-firing marks.
20	CYJLQWY-20	Bowl sherd; relatively thin, pure-white, dense body with virtually no inclusions; thin, glossy glaze extending to the base, white with a yellowish tint; two surviving large elongated spur marks on the interior floor; jade-ring base; low, thick ring foot with a steep inner bevel and spur-firing marks.
21	CYJLQWY-21	Base sherd of unidentified vessel form; relatively thick, grayish-white body with a few inclusions; thin, glossy interior glaze, white with a yellowish tint; three surviving large elongated spur marks on the interior floor; jade-ring base; low, thick ring foot with a steep inner bevel and spur-firing marks.
22	CYJLQWY-22	Rim sherd of unidentified vessel form; relatively thin, grayish-white, coarse body with numerous small black specks; thin, glossy glaze, white with a yellowish tint.

3. Analytical Methods and Results

The white porcelain samples were characterized by water-absorption testing and chemical-composition analysis.

3.1. Water-absorption Test: Method and Results

Water absorption was measured in accordance with the Chinese national standard GB/T 3810.3-2016, Test Methods of Ceramic Tiles-Part 3: Determination of Water Absorption, Apparent Porosity, and Bulk Density.

Water absorption was calculated using the following equation:

$$E = \left(\frac{m_2 - m_1}{m_1} \right) \times 100\%$$

Apparent porosity was calculated using the following equation:

$$P = \left(\frac{m_2 - m_1}{V} \right) \times 100\%$$

Analysis of water-absorption results

A total of 22 white porcelain samples (CYJLQWY1–CYJLQWY22) were tested. 19 samples had water-absorption values between 0.02% and 0.99%, with the dataset as a whole dominated by low values. This pattern indicates a very high degree of sintering, dense ceramic bodies, and very low porosity in the Longquanwu white porcelain (Table 2).

Table 2. Volume, water absorption, and apparent porosity of the white porcelain samples.

Sample ID	Mean dry mass (g)	Volume (cm ³)	Mean wet mass (g)	Water absorption	Apparent porosity
CYJLQWY1	0.21	0.40	0.21	0.36%	0.19%
CYJLQWY2	0.32	0.50	0.32	0.28%	0.18%
CYJLQWY3	0.34	0.50	0.34	0.34%	0.23%
CYJLQWY4	0.55	0.50	0.56	0.28%	0.30%
CYJLQWY5	0.36	0.30	0.36	0.27%	0.32%
CYJLQWY6	0.55	0.60	0.55	0.45%	0.41%
CYJLQWY7	0.24	0.30	0.24	0.16%	0.13%
CYJLQWY8	0.37	0.20	0.37	0.14%	0.25%
CYJLQWY9	0.54	0.60	0.54	0.13%	0.12%
CYJLQWY10	0.49	0.40	0.49	0.06%	0.07%
CYJLQWY11	0.46	0.60	0.46	0.15%	0.12%
CYJLQWY12	0.35	0.40	0.35	0.12%	0.11%
CYJLQWY13	0.27	0.30	0.28	0.72%	0.66%
CYJLQWY14	0.26	0.20	0.27	1.62%	2.12%
CYJLQWY15	0.27	0.30	0.27	0.39%	0.35%
CYJLQWY16	0.61	0.40	0.61	0.19%	0.29%
CYJLQWY17	0.72	0.40	0.72	0.11%	0.19%
CYJLQWY18	0.48	0.70	0.51	5.97%	4.08%
CYJLQWY19	0.45	0.30	0.45	0.07%	0.11%
CYJLQWY20	0.69	0.70	0.69	0.02%	0.02%
CYJLQWY21	0.61	0.40	0.62	0.99%	1.52%
CYJLQWY22	0.30	0.40	0.31	2.22%	1.68%

In archaeological and ceramic-technological studies, water absorption is an important indicator of firing temperature and the degree of body sintering. A water-absorption value below 1% is commonly taken to indicate relatively high firing temperatures and a well-sintered ceramic body.

CYJLQWY17, CYJLQWY19, and CYJLQWY20 yielded the lowest water-absorption values, at 0.11%, 0.07%, 0.02%, respectively. Their bodies are therefore among the densest in the assemblage and exhibit low apparent porosity, representing a group with a comparatively high degree of sintering. CYJLQWY5, CYJLQWY8, CYJLQWY9, CYJLQWY10, CYJLQWY11, CYJLQWY12, and

CYJLQWY16 likewise fall within a low range, indicating broadly consistent body densification across much of the assemblage.

By contrast, several samples show distinctly higher water-absorption values, including CYJLQWY13, CYJLQWY14, CYJLQWY18, CYJLQWY21, and CYJLQWY22. Their divergence from the remaining samples indicates a greater abundance of open pores and lower body density. CYJLQWY18 and CYJLQWY22 are particularly high. Macroscopic inspection also shows that both have relatively coarse bodies and should be classified as coarse white porcelain.

Overall, the experimental data show that the Caiyuan Street white porcelain generally has low water absorption, indicating good sintering quality and high body density. The high degree of sintering and stable physical properties provide material evidence for the advanced level of ceramic craftsmanship in Liao-period Beijing. The elevated values of a small number of samples also show that products attributed to the same kiln were not completely uniform in pore structure or firing quality. The water-absorption results therefore provide an important physical basis for interpreting technological variation in conjunction with chemical-composition data.

3.2. Chemical Compositions of Bodies and Glazes: Methods and Results

Analytical methods

Chemical analysis is fundamental to the scientific study of archaeological ceramics because it provides evidence for raw-material types and sources as well as manufacturing technology. The chemical compositions of the 22 white porcelain samples were determined by micro-X-ray fluorescence (μ -XRF) and energy-dispersive X-ray spectrometry (EDS). Major and minor oxides measured in the bodies and glazes included Na_2O , MgO , Al_2O_3 , SiO_2 , P_2O_5 , K_2O , CaO , TiO_2 , MnO , and Fe_2O_3 , providing a comprehensive characterization of body and glaze chemistry.

μ -XRF analysis was performed using an XGT-9000 instrument operated at 50 kV and 200 μA . EDS analysis was conducted with a TM4000 scanning electron microscope equipped with an energy-dispersive spectrometer at an accelerating voltage of 15 kV under medium vacuum (M). The acquisition time was 100 s for all measurements. Three separate points were analyzed on both the body and glaze of each sample, and the mean of the three measurements was used. The analytical data are presented.

4. Discussion

4.1. Chemical Compositions of Ceramic Bodies and Glazes

Analysis of the 22 white porcelain samples from Liao–Jin contexts at the Caiyuan Street Site, which are morphologically consistent with Longquanwu kiln products, shows that the bodies contain 24.62–39.84 wt% Al_2O_3 (mean 34.09 wt%) and 54.32–68.98 wt% SiO_2 (mean 58.64 wt%). This high-alumina, low-silica composition is characteristic of northern Chinese white porcelain. Fe_2O_3 and TiO_2 are the principal coloring oxides in the bodies. Fe_2O_3 is consistently below 1 wt%, whereas TiO_2 is somewhat higher, ranging from 0.72 to 1.87 wt%. Under an appropriate firing atmosphere the bodies appear relatively white, whereas firing under a more oxidizing atmosphere produces a white color with a yellowish tint. No slip layer is present between body and glaze. Na_2O , K_2O , MgO , and CaO act as fluxing components in the bodies. Na_2O and K_2O are comparatively high, with total R_2O values of 2.57–5.70, whereas MgO and CaO are lower, with total RO values of 0.46–1.62. The relatively high flux content promotes sintering and contributes to low water absorption. The high Al_2O_3 , Na_2O , and K_2O contents suggest that the body recipe may have combined kaolin with feldspar.

Following a systematic study of calcium-bearing glazes in ancient Chinese ceramics, Luo Hongjie and colleagues [6] proposed a classification based on the Seger formula $a\text{R}_2\text{O} \cdot b\text{RO} \cdot c\text{R}_2\text{O}_3 \cdot d\text{RO}_2$, in which R_2O and RO represent

alkali-metal oxides and alkaline-earth oxides, respectively, while R_2O_3 and RO_2 represent trivalent and tetravalent oxides. The coefficients a , b , c , and d are calculated after normalizing the total molar amount of basic oxides ($\text{R}_2\text{O} + \text{RO}$) to 1. Under this scheme, calcium glazes have $b \geq 0.76$, calcium–alkali glazes have $0.76 > b \geq 0.50$, and alkali–calcium glazes have $b < 0.50$. On this basis, CYJLQWY3, 6, 8, 13, and 18 are calcium glazes; CYJLQWY1, 4, 5, 9, 11, 12, 14, 17, 19, 20, 21, and 22 are calcium–alkali glazes; and CYJLQWY2, 7, 10, 15, and 16 are alkali–calcium glazes. The broad distribution of glaze types demonstrates substantial variation in glaze recipes and may indicate chronological differences among the vessels.

According to previous research, calcium–alkali glazes did not become established and widely used in southern China until more than five centuries later, in Southern Song imperial wares and Longquan celadon, whereas alkali–calcium glazes did not appear until the Yuan dynasty at Jingdezhen approximately seven centuries later and became more common in the Ming and Qing dynasties, although calcium–alkali glazes remained predominant [7]. Alkali–calcium glazes contain increased K_2O and reduced RO , which can improve firing behavior, for example by increasing glaze viscosity and thickness and producing a more lustrous, translucent, jade-like surface. This represents a significant technological development in glaze preparation. Whether the alkali–calcium recipes identified in the Liao-period white porcelain examined here were accidental products or deliberate choices by potters requires verification using a substantially larger sample.

The glazes contain 0.36–3.71 wt% Na_2O , 0.78–4.94 wt% MgO , 1.18–7.20 wt% K_2O , and 1.35–9.04 wt% CaO . The glaze of CYJLQWY9 contains 4.94 wt% MgO and 3.31 wt% CaO , giving $n(\text{Mg}):n(\text{Ca}) \approx 2$, while its P content is low at only 0.06 wt%. This composition may indicate the use of a Mg-rich inorganic ash material, possibly involving the addition of dolomite. The glaze of CYJLQWY16 contains 7.20 wt% K, suggesting the addition of a feldspathic material. P_2O_5 in glazes commonly derives from plant ash and varies widely here, from 0 to 1.09 wt%. Samples with low P may have used inorganic ash materials such as limestone, whereas samples with higher P may have incorporated organic ash such as plant ash. Fe_2O_3 is approximately 1 wt% and TiO_2 is below 1 wt% in the glazes. The low Fe and Ti contents indicate high-quality raw materials and mature processing, contributing to the white glaze color.

4.2. Provenance Signatures and Kiln Attribution

Because Longquanwu and Ding white porcelains were manufactured using similar techniques and Longquanwu imitated Ding wares during certain periods, visual characteristics alone cannot reliably distinguish the products of the two kiln centers. The present samples were therefore compared with white porcelain excavated from the Longquanwu kiln site and dated to the late Liao–early Jin period [8], as well as with chemical-composition data for Ding kiln white porcelain of the Song–Jin period [9]. Factor analysis was performed in IBM SPSS Statistics 27 using the major compositional variables Na, Mg, Al, Si, K, Ca, Ti, and Fe in the bodies and glazes.

Multivariate statistical analysis and the scatterplots of body and glaze compositions (Figs. 2 and 3) show that the 22 white

porcelain samples from the Liao-period strata at the Caiyuan Street Site cluster broadly with Liao–Jin white porcelain excavated from the Longquanwu kiln site in terms of body composition. In the Fe_2O_3 – TiO_2 plot, the Fe contents of the Longquanwu reference samples are widely dispersed and do not form a tight cluster with the Caiyuan Street samples; nevertheless, the Caiyuan Street samples largely fall within the Longquanwu compositional range, and the two groups show similar TiO_2 contents. By contrast, comparison with Song–Jin Ding kiln white porcelain [10] reveals substantial compositional differences, providing preliminary evidence that the analyzed samples were most likely products of the Longquanwu kiln.

Body compositions are relatively tightly clustered, whereas glaze compositions are more dispersed. Ceramic-body composition is generally constrained by local clay resources and is less strongly affected by deliberate human intervention; consequently, local geological signatures tend to produce tighter compositional groupings, and the Caiyuan Street bodies differ markedly from Ding kiln bodies. Glaze composition, by contrast, is more strongly influenced by recipe formulation and may reflect technological borrowing or exchange. The samples may also span a relatively broad chronological range, during which glaze recipes were not stable. Their glaze compositions are therefore more dispersed overall and differ less clearly from those of Ding kiln products.

The bodies contain a mean of 34.09 wt% Al_2O_3 and 58.64 wt% SiO_2 , placing them within the high-alumina, low-silica compositional group typical of northern Chinese white porcelain. Compared with Ding kiln white porcelain, the Caiyuan Street samples are distinguished by high Al_2O_3 and low SiO_2 , high Na_2O – K_2O and low MgO – CaO , and high TiO_2 and low Fe_2O_3 . In particular, the alkali-metal oxides Na_2O and K_2O are substantially higher than the alkaline-earth oxides MgO and CaO , while TiO_2 is relatively high and Fe_2O_3 is low. These characteristics constitute a set of compositional “fingerprints” that distinguish the bodies from Ding kiln white porcelain.

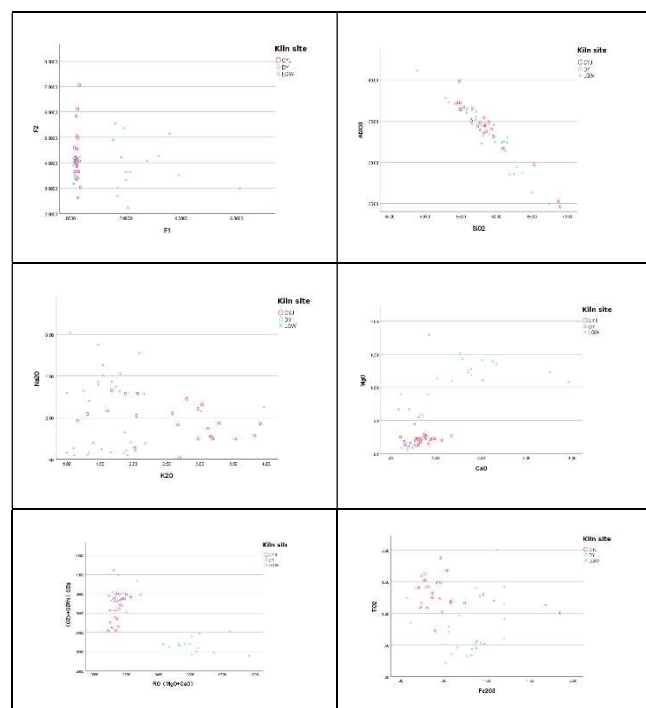


Fig. 2 Factor-analysis score plot and compositional scatterplots for the ceramic bodies.

The glazes are characterized by relatively low Al_2O_3 and high SiO_2 . Na_2O and K_2O are relatively high, while MgO and CaO show less pronounced differences among the groups. TiO_2 is relatively high, whereas Fe_2O_3 shows comparatively limited differences (Figs. 3).

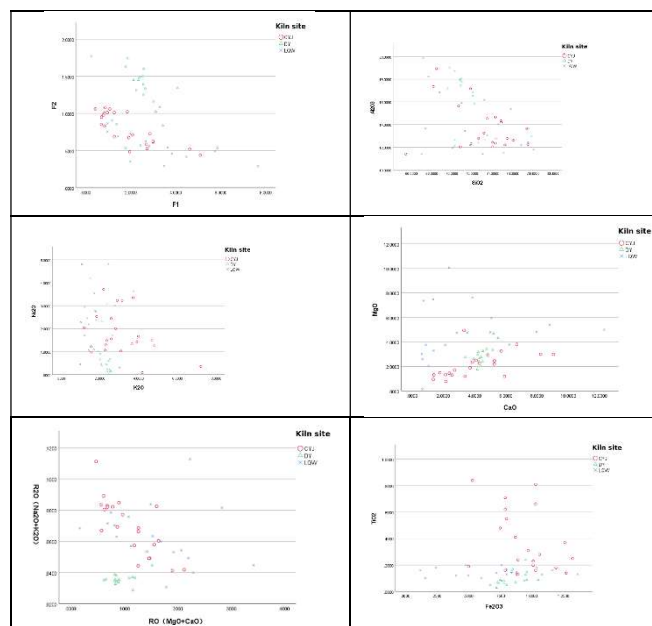


Fig. 3 Factor-analysis score plot and compositional scatterplots for the glazes.

Taken together, the systematic compositional differences indicate that the white porcelain excavated at the Caiyuan Street Site differs from the Ding kiln system in raw-material selection and formulation. Its technological characteristics are more consistent with the Longquanwu kiln production tradition in the Beijing region, providing clear archaeometric support for attribution to that kiln.

5. Conclusion

The Longquanwu kiln was an important ceramic-production site in Beijing during the Liao and Jin periods. This study reviewed its geographical setting, historical context, and principal product characteristics and conducted scientific analyses of 22 white porcelain samples excavated from the urban site of Jin Zhongdu. The main conclusions are as follows:

(1) The white porcelain excavated at the Caiyuan Street Site of Jin Zhongdu can be clearly distinguished from Ding kiln white porcelain on the basis of its scientific and technological characteristics. Its overall technological profile closely matches that of Longquanwu kiln white porcelain, indicating that the assemblage should be attributed to the Longquanwu kiln. This provides scientific evidence for identifying a local source of ceramics consumed at the urban site of Jin Zhongdu.

(2) The white porcelain bodies are generally dense and well sintered, with low water absorption, indicating relatively high firing temperatures and good overall physical properties. These characteristics reflect a mature level of porcelain production at non-imperial kilns in the Beijing region during the Liao dynasty. Variation among individual samples may relate to differences in raw-material levigation, forming techniques, firing regimes, or post-depositional burial

conditions.

(3) The bodies are chemically characterized by high Al_2O_3 and low SiO_2 , high Na_2O – K_2O and low MgO – CaO , and high TiO_2 and low Fe_2O_3 , suggesting a body formulation that may have combined kaolin with feldspathic minerals. The glazes belong to the broader calcium-bearing glaze system but are compositionally diverse, including calcium, calcium–alkali, and alkali–calcium types. This diversity may indicate that the samples were not produced at the same time, place, or firing batch; alternatively, it may reflect experimental glaze formulation or instability in raw-material supply at the Longquanwu kiln during the Liao period.

Relative to Ding kiln white porcelain of the Song–Jin period, the Caiyuan Street bodies are characterized by high Na_2O – K_2O , low MgO – CaO , high TiO_2 , and low Fe_2O_3 , whereas the glazes are characterized by low Al_2O_3 and high Na_2O – K_2O .

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