A Landmark in the History of Chinese Ceramics: The Invention of Blue-and-white Porcelain in the Tang Dynasty (618–907 A.D.)

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Abstract This study investigates the origin and development of Tang blue-and-white porcelain. Test samples consist of excavated shards of blue-and-white porcelain, white porcelain, Tang tricolor pottery, and blue-on-white pottery from the Tang strata of the Baihe and the Huangye kiln sites. The chemical compositions, firing temperatures, and physical properties were studied scientifically, and multivariate statistical analysis was applied to analyze the compositional data. The results show that Tang blue-and-white porcelain developed from a mature manufacturing technology of white porcelain in the late Tang. Moreover, the type of cobalt pigment used is similar to that used for blue-on-white pottery. This study contributes to our understanding of the invention of Tang blue-and-white porcelain.

Statement of significance In recent years, several shards of blue-and-white porcelain have been found in the late Tang strata of the Huangye and the Baihe kiln sites in Gongyi district of Henan Province (Henan Provincial Institute of Cultural Relics and Archaeology 2005, 17; 2007; 2009, 22). Notably, these are the only pieces of blue-and-white wares of the Tang dynasty that have been excavated at a kiln site. For the very first time, with data analysis of the chemical compositions and comparisons among pottery and porcelain throughout distinct time periods of the Tang Dynasty, this study explicates the invention of Tang blue-and-white porcelain from a scientific standpoint. Derived from Tang tricolor pottery, blue-on-white pottery and, especially, white porcelain production, raw materials and firing techniques lay the groundwork for the emergence of blue-and-white wares. The invention of Tang blue-and-white porcelain marks a crucial milestone in the developmental history of ancient Chinese ceramics.

Key words Huangye kiln; Baihe kiln; Tang blue-and-white porcelain; multivariate statistical analysis

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1 Introduction

The Tang Dynasty (618–907 A.D.) was a prosperous time of social development in ancient China, when the porcelain-making industry advanced rapidly. The porcelain made in that period was known for its great variety, varicolored glazes, and multiple vessel shapes. Productivity growth, technological improvement, social stability, cultural prosperity, and foreign exchange expansion provided proper economic and social conditions for the invention of blue-and-white porcelain in the Tang Dynasty.

Some evidence has shown that blue-and-white porcelain was successfully produced as early as the Tang Dynasty. However, few of the blue-and-white wares from the Tang Dynasty can be found in China because most have been exported abroad. Tang blue-and-white ware was discovered in the 1940s, but it was largely ignored until Tang blue-and-white plate and pillow shards were excavated in 1975 from the Tang City site in Yangzhou, which is a famous trade port in Jiangsu province. Another important finding occurred in 1998, when three pieces of intact Tang blue-and-white plates were found on the Indonesia Belitung shipwreck (Regina Krahl 2011, 209), providing specific clues for dating.

Listed as a National Key Cultural Relics Conservation Unit, the Gongyi kiln site covers the Baihe kiln site and the Huangye kiln site (Figure 1). The Gongyi kiln started firing porcelains in the North Dynasty...
(386–581 A.D.). The industry became prosperous in the Tang Dynasty (618–907 A.D.) and declined in the Song and Jin Dynasties (960–1234 A.D.). Archaeological excavations were conducted at the Baihe kiln site from 2005–2007 and at the Huangye kiln site from 2002–2004. A very small quantity of Tang blue-and-white shards was excavated from the late Tang stratum of the Gongyi kiln site. However, with the usage of archaeological stratigraphy, these shards can validate the time and place that the Tang blue-and-white was produced (Henan Provincial Institute of Cultural Relics and Archaeology 2005, 17; 2007; 2009, 22).

A study in the 1980s on Tang blue-and-white shards collected from the Yangzhou Tang City indicated that the raw materials of their bodies and glazes were similar to those of the Tang white porcelain from the Gongyi kiln site. Therefore, scientists drew the conclusion that Gongyi was the place of origin of Tang blue-and-white porcelain (Zhang et al. 1989). The discovery of Tang blue-and-white shards at the Gongyi kiln site two decades later supported this hypothesis.

This study systematically tests and analyzes samples of blue-and-white porcelain, white porcelain, Tang tricolor pottery, and blue-on-white pottery excavated from the Tang strata of the Huangye and the Baihe kiln sites, which will be helpful to fully and scientifically understand the invention of Tang blue-and-white wares.

2 Experimental
The Henan Provincial Institute of Cultural Relics and Archaeology provided 161 samples, including 40 white porcelain shards, 4 blue-and-white porcelain shards, and 8 Tang tricolor pottery shards, which were excavated from the Baihe kiln site of Gongyi. Additionally, samples from the Huangye kiln site of Gongyi were also provided, including 60 white porcelain shards, 1 blue-and-white porcelain shard, 33 blue-on-white pottery shards, and 15 Tang tricolor pottery shards. Blue-and-white ware is single firing porcelain with an under-glaze blue decoration. Blue-and-white porcelain has a well-sintered white body and is painted with cobalt pigment and coated with a high-fired transparent glaze. Blue-on-white pottery refers to white glazed pottery with over-glaze blue decoration. The microstructure and its physicochemical basis for the white porcelain from the Gongyi Kiln have been investigated (Li et al. 2011, 361–381). The archaeological information on the dating and provenience of the shards has been published (Henan Provincial Institute of Cultural Relics and Archaeology 2005, 2–22; 2007; 2009, 2–28).

The chemical composition of porcelain bodies and glazes is examined using energy-dispersive X-ray fluorescence (EDAX Eagle-III μProbe, USA). The calibration process involves several steps. First, a series of 13 standard samples are formulated using the standard geological minerals. With the test results of the 13 standard samples, the calibration curves are established for each element to represent the relationships between the intensity of the element characteristic peak and the element concentration. With the calibration curves available as references, the EDXRF data are calibrated accordingly.

The firing temperature of porcelain bodies is tested by a dilatometer (NETZSCH DIL 402 C, Germany). A
A multivariate statistics method is adopted to analyze the chemical composition data.

3 Results and Discussion

3.1 Tang blue-and-white porcelain

This was the first time Tang blue-and-white porcelain was found at a kiln site, so it suggested that Gongyi was the original production area of the earliest blue-and-white porcelain. Four shards of blue-and-white porcelain were excavated from the Baihe kiln site (Figure 2a–2d), but no intact blue-and-white vessels were found. The 4 shards include two bowls, a box-and-cover set and a pillow decorated with flower patterns. Similarly, only one shard of a blue-and-white pot was excavated from the Huangye kiln site (Figure 2e), and no intact blue-and-white vessels were discovered.

The lozenge-surrounded-by-foliage motif on the blue-and-white shard excavated from the Baihe kiln site is similar to the one excavated from the Tang City site and the one from the Belitung shipwreck (Figure 3), suggesting that the Gongyi kiln site in Henan Province was the birthplace and production area of Tang blue-and-white porcelain.

3.2 Raw materials of the body, glaze, and pigment for Tang blue-and-white porcelain from Gongyi

3.2.1 Body materials of Tang blue-and-white porcelain

Figure 5 shows the factor loading diagram of the major and minor chemical compositions (Na₂O, MgO, Al₂O₃, SiO₂, K₂O, CaO, TiO₂, and Fe₂O₃) of the bodies of Tang white porcelain, Tang blue-and-white porcelain and Tang tricolor pottery from the Baihe kiln site. The body material of Tang white porcelain differs from that of the Tang tricolor pottery but is similar to the Tang blue-and-white porcelain. The CaO and Fe₂O₃ contents of Tang tricolor pottery are much higher than that of the white porcelain.

Figure 6 presents the factor loading diagram of the major and minor chemical compositions of the bodies of Tang white porcelain, Tang blue-and-white porcelain, Tang tricolor pottery, and Tang blue-on-white pottery. A special variety of blue-on-white pottery (Figure 4), unearthed in the Middle and Late Tang strata of the Huangye kiln site, presumably served as the intermediate product between tricolor pottery and blue-and-white porcelain.

Figure 2 Blue-and-white shards from the Baihe kiln site (a)–(d) and the Huangye kiln site (e), late Tang.
pottery excavated from the Huangye kiln site. The Tang tricolor pottery body material is different from Tang white porcelain, and its CaO and Fe₂O₃ contents are much higher. In an analogy to the findings at the Baihe kiln site, body material of Tang blue-and-white porcelain is similar to that of Tang white porcelain. Additionally, the diagram shows that the body material of blue-on-white pottery from the late Tang stratum can be divided into two categories: one that is similar to the Tang tricolor pottery, and one that is similar to the Tang white porcelain.

The body material of the Tang blue-and-white porcelain is similar to that of the Tang white porcelain, and different from that of the Tang tricolor pottery (Figures 5 and 6), which implies that the body material selection and treatment by Tang potters differs between tricolor pottery and white porcelain. The body of the Tang tricolor is considered pottery, but that of white ware and blue-and-white ware is considered porcelain. The fact that the two parts of the body materials of the blue-on-white pottery are similar to that of Tang tricolor pottery and Tang white porcelain indicates the possibility that blue-on-white pottery is an intermediate product. Blue-on-white pottery, discovered from the middle-to-late Tang strata and in trash pits (Henan Provincial Institute of Cultural Relics and Archaeology 2005, 13; 2007), might be a new product developed by Tang potters based on the technology of Tang tricolor pottery.

3.2.2 Glazes of the Tang blue-and-white porcelain
The test results of the chemical compositions reveal that the glaze of Tang blue-and-white porcelain is not lead-based but is a calcium or calcium-alkali glaze, which is commonly found in white porcelain (Figures 7 and 8).

The glaze of Tang blue-and-white porcelain is similar to the Tang white porcelain glaze (Figures 6 and 7) and is much closer to the late Tang white porcelain glaze, indicating that all Tang blue-and-white shards from the Gongyi kiln site were unearthed from the late Tang stratum. Compared to early Tang white porcelain glaze that has low SiO₂ content, the glaze used in late Tang white porcelain has a significant increase in SiO₂ content. For white porcelain from both the Baihe and the Huangye kilns in the late Tang, the average SiO₂ content of the glaze is above 70wt%, which is the highest on record.

Four transparent glazes of Tang tricolor pottery and blue-on-white pottery are low-fired lead glazes with high PbO₂ content (Table 1), and their compositions are similar. The blue pigment has the characteristic compositions of Co and Cu. This fact is made clear by comparing the compositions of two glazes (Tables 1 and 2) because the transparent glaze turns into blue glaze with the addition of blue pigment. In comparison, the glazes of Tang blue-and-white porcelain and white porcelain are high-fired calcia-silicate glazes. Additionally, the blue pigment used in the Tang
blue-and-white porcelain is characterized by Co and 
Cu; therefore, it is likely to be the same type of blue 
pigment that was used for Tang tricolor pottery and 
blue-on-white pottery.

By analyzing the test results of the glazes, it can be 
seen that the Tang blue-and-white porcelain of the 
Gongyi kiln adopts the glaze of white porcelain. The 
blue-on-white pottery uses blue painting and utilizes 
lead glaze, which is the same glaze system as Tang tri-
color pottery. Combining the results of the bodies and 
glazes, it can be shown that the material base of Tang 
blue-and-white porcelain is Tang white porcelain 
because of the similar bodies and glazes. However, 
the production of the blue-on-white pottery is based 
on the Tang tricolor pottery, and the bodies of some 
artifacts have been improved because the dark body 
under the transparent lead glaze can affect the 
contrast decoration effect of the white glaze and the 
over-glazed blue decoration.

3.2.3 Pigment of Tang blue-and-white porcelain 
EDXRF is applied for the nondestructive analysis of 
blue-and-white porcelain, and the percentage of color-
ing elements in blue pigment is calculated according 
to the method mentioned in a previous article (Chen 
et al. 1978) (Table 3).

The blue pigment of Tang blue-and-white porce-
lain is a type of cobalt mineral that contains both Co 
and Cu. The Co content is very high, and the Mn and 
Fe contents are low. Additionally, there is little Cu. 
The source of the pigment of Tang blue-and-white is 
still unknown, and it is different from the blue 
pigment of the blue-and-white porcelains produced 
in Jingdezhen in the Yuan (1271–1368 A.D.), Ming 
(1368–1644 A.D.) and Qing (1644–1911 A.D.) dynasties,
which have a high Fe content and low Mn content or a high Mn content and low Fe content. Therefore, China’s blue-and-white porcelain has two independent origins, unrelated in time and place.

As shown in Figure 9, the blue pigments of Tang blue-and-white porcelain, Tang tricolor pottery, and blue-on-white pottery are the same type, i.e., cobalt minerals with coexistent Co and Cu. Compared to Tang tricolor pottery, the blue pigment of Tang blue-and-white porcelain has a higher CoO content. Furthermore, certain samples of blue-on-white pottery also show a high CoO content, indicating that the blue pigments utilized in Tang blue-and-white porcelain are similar to those of blue-on-white pottery.

### 3.3 Firing techniques of Tang blue-and-white porcelain of the Gongyi kiln

Because Tang blue-and-white porcelain samples are relatively scarce, their firing temperatures and physical properties were not measured. However, the average firing temperature of Tang white porcelains of the
Baihe kiln and Huangye kiln (seen in Figure 10) is 1247°C, which indicates that Tang blue-and-white porcelain’s firing temperature is probably approximately 1250°C. Similarly, the firing process is basically the same as white porcelain except for adding a painting process on the body surface and then using high-temperature single firing after glazing.

The test results demonstrate that the firing temperatures of blue-on-white pottery from the Huangye kiln site are approximately 1000°C (Table 4). Blue-on-white pottery adopts lead glaze and a twice firing process, which means putting green bodies into a kiln to biscuit fire first at approximately 1000°C (Table 4), then glazing with a lead glaze (Tables 1 and 2), and firing at a lower temperature. The whole process is similar to the firing process of Tang tricolor pottery.

### 3.4 The relationship between tricolor pottery, blue-on-white pottery, and blue-and-white porcelain

Both Tang tricolor pottery and blue-on-white pottery use lead glaze, which has a low melting point, and blue-on-white pottery adopts over-glaze decoration. Because the flow of lead glaze increases the bloom side and instability of the decorated patterns, the over-glazed blue patterns found so far only consist of simple points and lines (Figure 4). However, Tang blue-and-white porcelain adopts under-glaze decoration, which means painting on the green body, with transparent glaze on the top. In addition, all of the discovered Tang blue-and-white porcelain has flower-and-straw patterns composed by lines, which are more complex and finer than tricolor pottery and blue-on-white pottery.

Through the above analysis, the invention process of Tang blue-and-white porcelain can be summarized as follows (Figure 11).

### 4 Conclusion

The first appearance of Tang blue-and-white porcelain in Gongyi of Henan province of China was not an accident. The long-term development and inheritance of ceramics-making technologies is closely related to the rise and evolution of white porcelains, as well as the prosperity of Tang tricolor pottery, Tang blue-on-white pottery, and Tang blue-and-white porcelain. The body and glaze compositions and firing skills of Tang

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**Table 4** Physical properties and firing temperatures of the bodies of blue-on-white pottery samples excavated from the Huangye kiln site of Gongyi.

| No. | Volume density (g/cm³) | Water adsorption (%) | Apparent porosity (%) | Firing temperature (°C) |
|-----|------------------------|-----------------------|-----------------------|------------------------|
| 15–1| 1.94                   | 12.4                  | 24                    | 1110                   |
| 15–5| 1.94                   | 13.1                  | 25                    | 1120                   |
| 16–1| 1.83                   | 16.3                  | 30                    | 1050                   |
| 16–2| 1.79                   | 17.9                  | 32                    | 970                    |
| 16–4| 2.18                   | 4.2                   | 9                     | 1200                   |
| 16–8| 1.91                   | 13.3                  | 25                    | 1110                   |
| 16–9| 2.03                   | 10.5                  | 21                    | 1110                   |

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**Figure 11** Invention and evolution process of Tang blue-and-white porcelain.
blue-and-white are similar to those of the white porcelain of the late Tang. In addition, the type of pigment used is similar to that used for the upper-glaze blue decoration on white-glazed pottery. Therefore, in the late Tang dynasty, blue-and-white porcelain was invented based on the mature manufacturing technology derived from white porcelain production. Furthermore, blue-and-white porcelain breaks new ground for under-glaze cobalt decoration.

Conflicts of interest
The authors declare no conflicts of interest.

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Dr. Weidong Li is a professor at Shanghai Institute of Ceramics, Chinese Academy of Sciences, and is deputy director of the Ancient Ceramics Research Center. Her research interests include the scientific and technological evolution regularity of ancient ceramics, scientific conservation of silicate-based cultural relics, and replication of famous ancient porcelains.

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