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Introduction

In the sixth century AD, North China saw a major transformation of glazed ceramic technology from dark glazed earthenware toward translucent white porcelain, a change which constituted a milestone in Chinese ceramic history. The discovery of white porcelain initiated a new era of the so-called "southern green and northern white" ceramic production pattern in China (The Chinese Ceramic Society 1982: 181), and of the use of polychrome decoration such as cobalt blue on white base. This transformation represented a thorough evolution of ceramic technology, as almost all the factors of ceramic production were altered, including the body material, the glaze recipe, the firing conditions as well as manufacturing locations. This critical change involved the innovation of lead-glazed ceramics, the introduction of celadon into North China, and the emergence of white porcelain over merely one century. Nevertheless, the process of this dramatic transformation is unknown, due to insufficient understanding of the archaeological material from both typo-chronological and scientific perspectives. The present study is focused on the typo-chronology of three major categories of glazed ceramics discovered in sixth century North China and their manufacturing technologies. The chemical and mineralogical compositions of the body and the glaze, the glazing method, and the firing temperature and atmosphere were studied on the basis of analyses by optical microscopy, scanning electronic microscopy with energy-dispersive X-ray spectrometer (SEM-EDS), X-ray diffraction (XRD), and thermal expansion measurement. These provide insights into the pathways of transformation of northern lead-glazed earthenware and southern ash-glazed stoneware technologies towards the discovery of the earliest white porcelain. On this base, the social dynamics that drove the transformation of the ceramic technology and its impact on the succeeding period are discussed.

1.1. Categories of Glazed Ceramics

In North China, lead-glazed earthenware had been the dominant local glazed ceramic product for centuries. It was typically made of a common clay body and lead-fluxed glaze, then fired at a low temperature in the range of 700–900 °C, as the common clay is fusible, and lead is an effective flux (Zhang and Zhang 1980). This type of ceramics started to be manufactured from the late Warring States period (ca. 476–221 BC) in the third century BC (Lang and Cui 2017) and was mass-produced from the first century BC in the Western Han Dynasty (Chen 2005), with the production centre based in the middle Yellow River valley (Yang 2009). By the end of the Northern Dynasty, the production of lead-glazed ceramics had spread all over North China and reached the middle Yangtze River valley (Hsieh 1992). The technological characteristics of the lead-glazed ceramics are featured in the variety of the glaze colour. Different shades of brown, yellow, and green monochrome wares were seen in the North before the sixth century. From the sixth century, however, more varieties of lead-rich glaze are encountered, including pale yellow or even white-looking glazes, and polychrome combinations such as white and brown, white and green, and brown and green. The transformation of lead-glazed ceramics seems to display a trend toward increasing the whiteness of the artefacts. However, the process of this transformation, especially its chronological and technological trajectory, is unclear, and the impulse that drove this transformation in the sixth century, after nearly one thousand years of development, requires investigation.

Celadon production is generally accepted to have originated in South China, and it is the first and longest-lasting Chinese glazing technology. The history of Chinese glazes can be traced back to the early Bronze Age, at the Erlitou site near Luoyang, Henan province (ca. 18–16th century BC, Luo et al. 1996, Chen et al. 2002, Lu et al. 2012a) and Maqiao Culture site in Shanghai (ca. 20–16th century BC, Song et al. 1997). The glassy layer on the top of the highly fired body was identified as a result of vegetal ash, and thus the origin of Chinese glazing is seen as the outcome of fuel ash in the air inside the kiln reacting with the body, as biomass was the main fuel used for firing (Chen et al. 2002, Kerr and Wood 2004: 455). This led to the development of plant ash fluxed stoneware (the so-called proto porcelain) in the Shang Dynasty in the 17th century BC, when large scale production at proto-porcelain kiln sites was discovered in the lower Yangtze River delta. There are thus nearly 4000 years since the first high-fired glazed stoneware was successfully created in southeast China (Yin et al. 2011; Zhejiang Institute of Archaeology et al. 2011; Zhang 2016), and it was the only glazed ceramics achieved in the first 1500 years. Celadon is seen as a mature form of proto porcelain after 2000 years development, which was achieved in the Eastern Han Dynasty in the third century AD (The Chinese Ceramic Society 1982: 77; Li 1978). It should be noted that technically there is no fundamental difference between the proto-porcelain and celadon. The improvement from proto porcelain to celadon is presented by the refinement of the raw material and improvement of the firing temperature (Li 1978). In contrast to lead-glazed ceramics, celadon production is mainly a feature of southern culture, taking place in the whole of South China and represented in most areas to the south of the Yangtze River valley. Celadon production cannot be identified in the North before the sixth century AD, although artefacts of this type have been found from northern burials ever since its invention in the

Bronze Age. The southern celadon is made from porcelain stone, an altered igneous rock composed mainly of quartz and sericite with a small content of kaolinite, regardless in which part of South China it was produced, and the glaze is always fluxed with calcareous plant ash. Celadon needs to be fired at a high temperature in excess of 1150 °C to mature the body and glaze (Wang et al. 2014).

White porcelain discovered at the end of the sixth century in North China is a ground-breaking innovation which emerged out of the extremely long history of celadon production. Porcelain plays a unique role in the history of ceramics in China and is the "most distinguishing contribution to the world ceramics" (Kerr and Wood 2004: 146). Despite the divide line between the white stoneware and true porcelain is somewhat blurry in China, some white wares produced in the end of the sixth century already obtained high whiteness, refractoriness and translucency in Gongyi and Xingtai in Henan and Hebei provinces (Li et al. 1987; Chen et al. 1990), which place many early examples as porcelain. When it was first made, the pure white body and white/translucent glaze represented a new type of ceramics with very desirable properties. For example, Xing ware, an early porcelain type, was described as "snow" by Lu Yu, writing in *The Classic of Tea* (AD 760 – 780). In the same source, it was also described as "silver" which might imply that at least one of the motives of producing white porcelain was to imitate or evoke the value of silver ware. Furthermore, the introduction of a white base supplied the fundamental ground needed for colour decoration in later well-known ceramics, as painting is much more vivid and practical on a white background than on other colours, which is demonstrated by the fact that even high quality monochrome ceramics (celadon and brown, yellow, or green glazed pottery) became subsidiary to polychrome types (iron brown painting, Sancai, Blue-and-White, red-and-green, five-colour, famille rose, etc.) after the emergence of white porcelain. It is noteworthy that this first porcelain in the world is technically made with kaolinitic clay and fired to very high temperature in North China, which constitute a consistent technological characteristic until the invasion of Mongol and gradually disappeared with the "Harrying of the North" after the 13th century. On the other hand, the manufacture of white porcelain was introduced to the South in the late 9th early 10th century at sites such as Fanchang and Jingdezhen in south Anhui and north Jiangxi provinces. Due to the different geological condition, the southern porcelain was made with a quartz-hydromica material with a small content of natural kaolinite, similar to the southern stoneware (Tite et al. 2012).

Therefore, the emergence of porcelain in North China rather than South China at the end of the sixth century seems to be an abrupt development, since technically white porcelain can be produced in the South and appears more similar to celadon in terms of the refractory body, ash glaze, and high firing temperature. The high-fired, quartz-rich and ash-glazed stoneware had been produced in the South for more than 2000 years, but the ceramic manufacture technology in the North had been based upon low-fired lead-rich glazes, which seem to bear little relation with porcelain and celadon production. The reason why white porcelain was discovered in North China and how this technological innovation materialised are our major concerns in this project.

1.2. Current Opinion on Early Porcelain

Berthold Laufer first attempted to discuss the beginning of porcelain (1917) based on the glazed ceramics in the Han Dynasty. He noticed the difference between the low fired earthenware and the high fired stoneware, which is the first time that the stoneware was suggested as an initial form of porcelain. With the further understanding of this high fired ash glazed stoneware, the 'abrupt' beginning of the manufacture of porcelain in North China became a subject of debate, since it was acknowledged that high-fired ash-glazed stonewares were mainly made in South China. Chen Wanli (1956) suggested that celadon production might have started in the late Northern Wei Dynasty, as the celadon lotus jars discovered from the burials of the Feng clan in Jingxian, Hebei province, were probably dated to the 530s. This suggestion was accepted by Feng Xianming (1958) and became the main point of view afterwards. Feng further pointed out that the production of celadon can be confirmed at the kiln sites in Hebei and Henan provinces at the end of the Northern Dynasty and Sui Dynasty (570s-). Later, in the 1980s, the Chinese Ceramic Society (1982, 162–166) presented the production of celadon and porcelain in North China following the arguments made earlier by Chen and Feng, and suggested that white porcelain was developed out of celadon, which was the first time that their technological relationship was discussed. This point of argument was accepted as the basis of archaeometric research in the 20th century. Samples were obtained from the Xing, Ding, and Gongyi kiln sites, and analyses of materials were undertaken to identify the characteristics of white porcelain (Zhang et al. 1983; Li and Guo 1987; Li et al. 1987, Chen et al. 1990; Zhang et al. 1992). However, due to the limitation of the archaeological material, almost all of the work has concerned the mature white porcelain post-dating the Sui Dynasty, the analysis of early northern celadon was not developed. Therefore, the trajectory of the technological transformation has not been discussed properly in this stage.

It was from the 1990s that scholars started to challenge the arguments mentioned above. Hsieh (1994) compared the northern burial ceramic objects with southern products, pointed out their similarity, and suggested caution regarding the provenance of the celadon wares discovered in the North before their production gets confirmed at northern kiln sites. Guo and Zhang (1997) further compared some Northern Wei burial objects with southern celadon, and inferred that they were all southern products, and that a local production of celadon did not start until the Eastern Wei and Northern Qi Dynasties from the second half of the sixth century.

In the 21st century, the discussion on this topic moved into a new stage. Discoveries at the Luoyang city site suggested that not only celadon, but also white porcelain, were possibly produced in the Northern Wei Dynasty in the early sixth century (CASS 2009, Liu and Qian 2009). Similar wares discovered from the Baihe kiln site in Gongyi, Henan, were thereafter believed to be produced in the early 6th century (Henan Institute of Archaeology et al. 2009, Henan Institute of Archaeology et al., 2011). Samples from the Baihe kiln site has been studied and published by Li et al., 2016 and Luo et al., 2017, which are important reference regarding the properties of the early porcelain and its relationship with the northern celadon. However, this bold idea was immediately criticised, as Mori (2009) compared the products of the Baihe kiln, which had been uncovered in the excavation of Luoyang city, with objects from burials, suggesting that the Baihe production cannot be earlier than the Sui Dynasty. This meant these objects were more likely dated to the end of the sixth century or even the early seventh century. The archeaometric research to porcelain were mostly about the technological relationship between the Xing, Gongyi and Ding products (Zhu et al. 2010, Li et al.2010, Lu et al. 2012, Cui et al. 2012a&b), the discussion between different technological categories were barely mentioned except Li et al. 2016 and Ma et al. 2018, mainly on celadon and porcelain.

The significance of lead-glazed ceramics has been more concerned in the past two decades. Although Sato (1973) first suggested the white wares from the tomb of Fan Cui (AD 575, Henan Museum 1972) might be low fired glazed pottery, they have been generally considered as the earliest examples of white porcelain as suggested by the Chinese Ceramic Society (1982), which caused a long-term confusion in the study of this topic. This point of view was not challenged until the 21st century, when Kamei (2004), Hasebe (2008) and Mori (2009) started to review the origin of the white porcelain and believed the Fan Cui white wares should be lead-glazed. The Chinese Ceramic Society noticed that there was a revival of the lead-glazed ceramics production after the Northern Wei Dynasty, which can be seen from the luxuriously decorated appearance, in various colours, of some artefacts. The research of Kobayashi (2009, 2012) and Hsieh (2014) highlighted the significance of these pale coloured wares, to the transformation of the ceramic technology in the sixth century. From 2010, the discovery of the Caocun kiln site near the Ye city site threw light on research in this area, allowing a more specific study on the transformation of lead-glazed ceramics, initial analysis have revealed that the main products are lead-glazed (Zhang et al. 2013, Yan et al. 2018), meanwhile, white sherds from tombs in Anyang were analysed by Wang et al. (2010) and identified as lead-glazed. It is until then that the Fan Cui wares were more accepted as lead-glazed wares rather than porcelain, although material property of these wares has not been identified with scientific approach yet. The present work suggests that these lead-glazed wares may imply a new pathway of the development of early white porcelain. Therefore, it is essential to review the ceramic material produced in sixth century North China from both an archaeological and a materials science perspective, in order to obtain a robust understanding of the technical transformation of the ceramics.

1.3. Research Questions

The present project is concerned with the trajectory of the technological transformation of glazed ceramics in sixth century North China. It focuses on how white porcelain came into being from the combination of the development of local lead-glazed earthenware with the introduction of southern celadon, studied from archaeological and materials science perspectives. The research topic requires thorough examination into the material that was used for the bodies and glazes for different categories of ceramics, their development sequence and the improvement of the firing technology. The process of how the body and glaze were decolourised toward porcelain and why this happened in the North, where the technological tradition had been distinctive, are the main concerns of this research. There are two main research questions, which will be addressed through a number of specific research objectives:

1.3.1. What was the pathway of the technological transformation of glazed ceramics from a materials science perspective?

The dramatic transformation from dark lead-glazed earthenware to white porcelain in the sixth century North China has been observed by previous research, but how this transformation was materialised is to be studied from material science perspective. It is intended to address the route of this technological evolution and the reason why white porcelain was first developed in the North rather than in the South by comparing the raw materials and technology of the three ceramic categories. The main concerns of this study involve with these aspects:

- Differentiation of the different categories of glazed ceramics produced in sixth century North China.
- Identification of the material characteristics of each category, including raw materials, recipe, and firing technology.
- Characterisation of the spatio-temporal diversities and correlations of the three categories.
- Comparison with literature data of southern wares.

1.3.2. What was the social impulse driving the emergence and popularity of white porcelain?

If technical innovation is considered as the fundamental and internal impetus of the transformation of ceramic production toward white porcelain, what was the external impulse? The social motivation that drove the emergence of white porcelain is another major concern of this study. These questions will be addressed through a number of research objectives:

- Identification of the consumption contexts of glazed ceramics and the status of the consumers through literature and archaeology research.
- Comparison of the consumption of lead-glazed wares before and after their transformation.
- Comparison of the contexts of lead-glazed white wares and early white porcelain.
- Identification of any changes to the trade in celadon from the South to the North following the introduction of high-fired ceramics in the North.

1.4. Originality of the Project

The investigation of ceramic manufacture in sixth century North China is constrained from a fundamental insufficient understanding of the different technological categories and their development trajectories. Previous research based upon this insufficient understanding always had two critical problems. The first of these involved the amalgamation of different technical groups, such as mistaking lead-glazed ceramics for celadon, leading to the problematic discussion of the northern celadon production; or regarding it as white porcelain, suggesting that the production of porcelain started from the beginning of the sixth century; or even mistaking southern celadon as northern, leading to the assumption that celadon started to be produced in late fifth century. A robust discussion on this technical innovation should be based upon a solid discrimination of the three groups in accordance with a materials science approach. Secondly, a reliable archaeological development sequence is yet to be established for the discussion of the relationships between different technical categories. At some crucial points, this issue with chronology will lead to a completely different interpretation of the technological transformation of the ceramics. The present research aims to overcome these problems by two original approaches:

1. A thorough examination of carefully selected archaeological material. The confusion regarding the production of celadon and lead-glazed ceramics is mainly due to a limited understanding of the sixth century kiln sites in the North. For this project, intensive field surveys have been undertaken in the Shandong, Hebei, Henan, and Shaanxi provinces to: (a) Confirm the possible production locations and dating of the sixth century glazed ceramics in North China ; (b) To establish a base line for the differentiation of lead-rich glazed wares from ash-glazed celadon and porcelain by in-situ pXRF analysis of some representative objects, to further help establishing the typo-chronological sequence of the burial objects. Furthermore, funerary assemblages with accurate dating information, such as tombs which in medieval China always include epitaph stones, have been studied thoroughly.
2. Scientific analysis to characterise the material properties of each technological group and their development pathway. SEM-EDS, XRD, and thermal expansion analyses have been undertaken to understand the material properties of the different categories. This is the first time that the three types of ceramics under consideration are compared at the same standards in terms of raw material, recipe, and firing technology. Such a thorough comparison which is crucial to the study of the technological transformation, has not been conducted to date. Consequently, the present study is the first time that the raw material and technology of the glazed ceramics of the period have been discussed thoroughly based on the results of material analysis.

A discussion based upon archaeological and materials science research leads to an improved understanding of the role that glazed ceramics played in the sixth century, the integration of different ceramic technology, the interaction between the South and the North, and the impetus from outside China. As a result, an explanation as to why the white wares were made in North China in the end of the sixth century out of the development of the lead-glazed earthenware over one hundred year is attempted at the conclusions of this project. The combination of microscopic observation with macroscopic interpretation is original in the study of this field.