Parallel developments in Chinese porcelain technology in the 13th-14th centuries AD

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Abstract - By the 14th century AD, Jingdezhen in Jiangxi province and the Longquan region of Zhejiang province were China’s main centres for the manufacture of porcellaneous wares. Jingdezhen specialised in blue and white porcelain, while the Longquan kilns typically used opaque porcellanous bodies, and smooth and thick, greenish celadon glazes. A pattern of parallel technological development is evident at Jingdezhen and Longquan in the 13th-14th centuries, but probably driven by rather different causes. Jingdezhen is representative of a simpler and more local technological history that seems entirely southern. Longquan however adopted a glaze-type that had already seen many prestigious applications in north China. Unlike the white-bodied Jingdezhen wares, the Longquan bodies were sometimes deliberately discoloured with red clays, perhaps to harmonise with their jade-like greenish glazes.

1. Introduction
In the history of Chinese ceramics, two giant kiln complexes have dominated the mass production and export of high-fired wares - namely Jingdezhen in Jiangxi province and the Longquan region of Zhejiang province. Both sites are located in south China and in adjoining provinces. Jiangxi is land-locked, but Zhejiang has a long rocky coastline that borders the East China Sea. For centuries, Jingdezhen's main production has been blue and white porcelain, while the Longquan kilns specialised in grey-bodied porcellaneous wares with thick greenish glazes (Li Dejin 1994; Carswell 2000).

The huge productions of both Jingdezhen and Longquan wares were managed by what were essentially craft techniques — that is mainly by throwing on the potter's wheel and by hand-moulding, using plastic clay pressed into porous clay moulds. Firing was achieved in large high-temperature wood-burning kilns of simple but subtle design (Li Dejin 1994; Xiang Hai Tang 1995). Any equipment used tended to be straightforward, such as water-powered trip-hammers for pulverising rocky raw materials, and settling tanks for separating the powdered stones. However, within these craft-based workshops, extensive division of labour was often practised, and a single piece of blue and white porcelain, for example, may have passed through some seventy pairs of hands in the early 18th century (Du Halde 1736).

Despite the important visual differences between Jingdezhen blue-and-white and Longquan celadon wares, both kiln sites used similar raw materials for their clay bodies — namely low-iron rocks consisting largely of quartz and hydromica, known as cishi (porcelain stone) in China (Vogt 1900; Stannard 1986). As hydromica has a composition and crystal structure close to the clay mineral kaolinite, the rock could be rendered plastic by crushing, followed by levigation. At Jingdezhen, the cishi material was often mixed with lesser amounts of a white-firing primary clay known as gaoling (kaolin), while at Longquan 10 to 20% of primary red clay often rendered the near-white porcelain stone grey and non-translucient, or less pure rocks were used unmodified (Vogt 1900; Chou Jen et al. 1973). During firing, the more ferruginous Longquan material could re-oxidise superficially to a rust-red colour when unglazed — an effect that contrasted admirably with the thick, jade-like glazes applied to the wares.

2. Southern greenware: a common background to Jingdezhen and Longquan wares
In terms of the ceramics that they replaced, both Jingdezhen white porcelains and porcellaneous Longquan celadon wares shared a common ancestry — namely a stoneware known generically as 'southern greenware' (Guo Yain-yi et al. 1980). This was an opaque, grey-bodied material with a thin grey-green glaze. Like the porcellaneous materials that came to replace them, south Chinese greenwears often used rocky materials as the bases for their bodies. These tended to be pulverised and 'washed' microgranites that were already in a state of decomposition.
from chemical weathering. Rocks of this type are abundant throughout China’s southern provinces (Wood et al. 2005).

The same (or similar) processed rocks were mixed with about 40% of calcareous wood ash to make thin grey-green stoneware glazes (Wood et al. 2005, 194-5). The main kiln type used for the southern greenware industries dated from the Bronze Age and consisted essentially of long sloping tunnels built up hillsides (Xiang Hai Tang 1995). These wood-burning kilns were fired by large fire-boxes at the kilns’ feet, followed by successive side-stoking through ‘ports’ along the kilns’ sides. By the 12th century AD, these long (‘dragon’) kilns were approaching 140 metres in length, although kilns of 20-40 metres were perhaps more typical (Zeng Fang 1997, 30-2).

Just such a ‘southern greenware’ technology was operating at Jingdezhen in the early 10th century, when a white-firing porcelain stone was discovered there in the form of a compacted volcanic ash — a natural mixture of quartz, hydromica, and a small amount of kaolinite (Wood 1978; 1986). After processing, this gave a complete white-firing translucent porcelain body. As the usefulness of this material was established, it gradually replaced the old green-grey stonewares of the district. Eventually, limestone displaced calcareous wood-ash as the main glaze-flux at Jingdezhen, and plain bluish-white porcelains of great quality were developed from these two materials — using a plastic porcelain stone for the body and the same rock mixed with limestone for the glaze. This material is known as qingbai ware.

In the late 12th century, the clay-rich material gaoling started to be added to the Jingdezhen body, allowing more fusible and less plastic porcelain stones richer in soda feldspar (albite) to be exploited (Tite et al. 1984; Wood 2000b). Sometime in the 1320s, underglaze-blue painting with an imported iron-cobalt ore was introduced, to create the first Jingdezhen blue and white wares (Liu Xinyuan 1993). At much the same time, Jingdezhen potters turned from using their rather fluid lime-glazes and semi-opaque alkaline-lime ‘Shufu’ glazes to those of the lime-alkali type. These latter compositions had sufficient transparency to show the underglaze painting clearly, but also sufficient viscosity to prevent the blue cobalt pigments spreading into the molten glazes at high temperatures.

These were the main milestones in Jingdezhen’s technological history — from the traditional southern greenwares of the early 10th century AD, through qingbai and Shufu wares, to the blue and white porcelains of the 14th century.

3. The origins of Longquan celadon wares

In the west, the technological history of Jingdezhen has attracted a good deal of attention, as its wares are more familiar, and their influences on European porcelain history so profound. In contrast, the origins of Longquan porcellaneous celadon ware are less clear-cut. In particular, a material previously known as di ware seems to represent an early use of porcellaneous materials at Longquan (Chou Jen et al. 1973; Vandiver and Kingery 1986; Ren Shilong 1994), and the understanding of di ware appears to be the key to Longquan’s later porcellaneous productions.

4. Di wares and Longquan celadons compared

In Chinese, di means ‘younger brother’, while ge means ‘older brother’. According to a story written in the first half of the 16th century by Lu Shen in his Chunfengtang suibi and repeated many times in Ming and Qing literature (Zhu Bojian 1998, 21-3, 41-3), in the Song dynasty there were two brothers, Zhang Sheng the first and Zhang Sheng the second, native of Chuzhou, who both worked at the Lutian (today’s Dayao) kilns in Longquan. The greenware produced by the younger brother had the jade-like quality typical of Guan ware, while that fired by the older sibling was lighter in colour and was called ge ware. Because the story first appeared three hundred years after the manufacturing of this type of ware, it is understandably treated with scepticism by modern scholars. For this reason, the term di has rather fallen into desuetude. However, as it is associated with a very specific type of Southern Song Longquan celadon of exceptional quality (a key subject in this paper), it seems suitable for this discussion.

The di ware body-material was based on a near-white porcelain stone — a significant departure from the traditional grey-bodied southern greenware that had been the standard material in the Longquan area for most of the 12th century (Chou Jen et al. 1973). The bluish di ware glazes were also unusually thick, and, like later Longquan wares, were applied in a series of thin coats to maximise both depth and overall smoothness (Sundius and Steger 1963, 430). A further parallel between di wares and the later Longquan celadons lay in the use of lime-alkali glazes. This was a more sophisticated glaze-type than the old ash-rich compositions of the region, with their predominantly calcareous fluxes. These earlier, ash-fluxed glazes are known generally as ‘lime glazes’ (Zhang Fukang 1986). In lime-alkali glazes, the calcium oxide content is almost halved, and the alkalis (potassium and sodium oxides) increased somewhat in compensation. These changes resulted in stable and more viscous glazes with a smooth jade-like nature.

Thus, with its porcellaneous body and its smooth and thick lime-alkali glaze applied in many layers, di ware embodied three essential principles that were so successfully exploited in the later Longquan celadon production. All of this raises the following key questions: How did di ware come to be made at Longquan? And what were the origins of this sophisticated material that appeared fully-formed in a rather remote ceramics-producing region of Zhejiang province?

Perhaps the best approach to these problems is to divide the discussion into two parts. The first concerns the origin of (ie bluish lime-alkali glaze used on di ware, together with its multi-layer application. The second considers the introduction of white porcelain stone as a body material to the Longquan region.

5. The di ware glaze

Research by the present authors and colleagues has traced the background of the di ware glaze to the 10th century AD Huangbao kiln site in north China, hundreds of miles to the north-east of the Longquan region (Rastelli et al. 2002;
Wood et al. 2004a; 2004b). Huangbao was part of the great Yaozhou kiln complex in Shaanxi province that was established during the Tang dynasty (618-907). In the early 10th century AD, Huangbao’s productions included very high quality grey-bodied stonewares bearing thick bluish celadon glazes of both the lime and the lime-alkali types (Fig. 1). From the Huangbao kiln complex (which ran for some three miles along the Qishui river), this technology seems to have spread westwards within north China to three important kiln sites in the Henan province, known as Qingliangsi, Wenmiao, and Zhanggongxiang (Zhu Wenli and Zhu Yufeng 2002; Henansheng 2008). In the late 11th and early 12th centuries, all three kiln centres produced a type of fine bluish celadon ware that is known as Ru ware.

Many examples of Ru ware were true imperial ceramics, and commissioned for use within the palaces of the Northern Song capital of Kaifeng. Once again, both lime and lime-alkali compositions were adopted as compositional bases for the blue-green Ru ware glazes (Henansheng 2008, Tables 1-2, 447-8).

In 1127 AD, north China fell to the Jurchen Tartars. The surviving imperial court fled to south China and eventually established a new provisional capital at Hangzhou in the northern Zhejiang province in 1138.

In the later 1130s and early 1140s, the displaced imperial household commissioned two nearby southern greenware kilns (Silongkou and Dilingtou) to make ritual wares for the court - no doubt stipulating the use of the ‘imperial quality’ bluish celadon glazes with which they were already familiar (Jin Zhiwei and Chen Huqing 2005). Unfortunately these ‘official’ yue wares seem to have lacked the sophistication and exemplary craftsmanship of the true Ru wares of north China (Fig. 2) (Wood et al. 2004a, 222-3).

Nonetheless, and with the proper establishment of the new Southern Song capital in Hangzhou, the situation improved. Within Hangzhou itself, and actually within the grounds of the new imperial palace, an official kiln was established specifically to recreate the finest quality Ru wares of north China. Technologically and aesthetically, the venture was a triumph — despite the potters’ having to work within an entirely different geological domain (Wood 2000a; Li Jiazhi et al. 2001). Given the superlative quality of these new Hangzhou ‘official’ wares, it seems safe to assume that refugee craftsmen from the north were involved in their creation. This new ware of Hangzhou is now known as ‘Guan ware’ (i.e., ‘official’ ware) or, more accurately, ‘Southern Guan ware’, as ‘Northern Guan ware’ (an exceptionally fine style of Ru ware) had already been developed in the north a few years before its production was curtailed by the Tartar invasion (Krahl 1993). The establishment of the Guan ware kiln in Hangzhou is now dated to about 1145 AD, and its site, located in a steep wooded valley at Laohudong (Old Tiger Cave) was finally discovered and excavated in 1996 (Du Zhengxian 2002; Qin Dashu and Du Zhixingan 2004), after some decades of fruitless exploration (Fig. 3).

What makes Hangzhou Guan ware so special is the extraordinary combination of glaze and form achieved by its makers. The thick, bluish lime and lime-alkali glazes applied to the wares are of outstanding quality and the forms tend to follow Ru ware designs quite closely.

### Table 1. Blue celadon glazes of the lime-alkali type from 10th century Yaozhou to 13th century Longquan (Analyses from Wood et al. 2004a, 225 (SEM - WDA); Zhu Wenli and Zhu Yufeng 2002, 448 (PIXE); Li Jiazhi et al. 2001, 35 (EPMA); Vandiver and Kingery 1986, 188 (SEM - EDA)).

<table>
<thead>
<tr>
<th></th>
<th>Na₂O</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>CaO</th>
<th>TiO₂</th>
<th>MnO</th>
<th>FeO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early 10th C Yaozhou ware</td>
<td>0.3</td>
<td>1.4</td>
<td>15.4</td>
<td>69.9</td>
<td>0.5</td>
<td>2.9</td>
<td>8.1</td>
<td>0.1</td>
<td>0.1</td>
<td>1.5</td>
</tr>
<tr>
<td>11th C Wenmiao Ru ware</td>
<td>n.d</td>
<td>n.d</td>
<td>14.2</td>
<td>67.7</td>
<td>0.3</td>
<td>3.9</td>
<td>10</td>
<td>0.2</td>
<td>0.07</td>
<td>2.1</td>
</tr>
<tr>
<td>12th C Zhanggongxiang Ru ware</td>
<td>n.d</td>
<td>n.d</td>
<td>14.7</td>
<td>66.1</td>
<td>0.7</td>
<td>4.1</td>
<td>10.8</td>
<td>0.2</td>
<td>0.06</td>
<td>1.7</td>
</tr>
<tr>
<td>12th C Laohudong Guan ware</td>
<td>0.4</td>
<td>0.7</td>
<td>15.2</td>
<td>67.4</td>
<td>0.6</td>
<td>4.2</td>
<td>9.6</td>
<td>0.1</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Early 13th C Longquan Guan ware</td>
<td>0.2</td>
<td>0.8</td>
<td>15.9</td>
<td>66.0</td>
<td>n.d.</td>
<td>4.2</td>
<td>12.1</td>
<td>0.2</td>
<td>0.03</td>
<td>1.0</td>
</tr>
<tr>
<td>Early 13th C Longquan di ware</td>
<td>0.1</td>
<td>0.6</td>
<td>14.3</td>
<td>67.2</td>
<td>0.2</td>
<td>4.2</td>
<td>10</td>
<td>n.d.</td>
<td>0.1</td>
<td>1.3</td>
</tr>
</tbody>
</table>
These forms are an eclectic mixture of the most valuable vessel shapes of the time, and include copies of earlier Chinese bronzes, of imported Islamic glass, of fine Northern Song gold and silver vessels, and of Chinese lacquer wares of supremely simple design.

However, Hangzhou Guan ware soon came to differ from northern Ru wares in two important regards — the thickness of its glaze and the colour of its body material. With regard to its glazes, Southern Guan wares exploited to an unprecedented extent the potentials of multi-layer application. Indeed, with some examples the bodies are wafer-thin, but the glazes can be thicker even than the bodies beneath, with some wares appearing to consist almost entirely of glaze (Sundius and Steger 1963, 438; Li Jiazhi et al. 2001, 32). As for the body material, this was initially pale grey stoneware, much like Ru ware, but it soon became much darker, through the use of more ferruginous clays in the recipes. In some examples of Hangzhou Guan ware, the bodies are almost black.


<table>
<thead>
<tr>
<th>Date (AD)</th>
<th>North China (Site, province)</th>
<th>Ware type</th>
<th>Lime glazes</th>
<th>Lime-alkali glazes</th>
</tr>
</thead>
<tbody>
<tr>
<td>10th C</td>
<td>Yaozhou, Shaanxi</td>
<td>Yaozhou celadon</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Late 11th early 12th C</td>
<td>Qingliangsi, Henan</td>
<td>Ru ware</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Late 11th C</td>
<td>Wenmiao, Henan</td>
<td>Ru ware</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Early 12th C</td>
<td>Zhanggongxiang, Henan</td>
<td>Ru ware (Guan Ru?)</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

Movement of imperial court to south China after Jurchen invasion of north China

1131-1138  Silongkou, n. Zhejiang  ‘official’ Yue ware  ?  ?
1136-1145  Dilingtou, n. Zhejiang  ‘official’ Yue ware  ?  ?
1145 - 13th C  Laohudong, Hangzhou, n. Zhejiang  Guan ware  yes (most)  Yes (a few)
Later 12th - 13th C  Jiaotanxia, Hangzhou, n. Zhejiang  Guan ware  Yes  Yes
1180s to mid 13th C  Guan ware  Dayao, and Xikou, s.w. Zhejiang  Yes  Yes
1180s to mid 13th C  di ware  Dayao, and Xikou, s.w. Zhejiang  No  Yes

These forms are an eclectic mixture of the most valuable vessel shapes of the time, and include copies of earlier Chinese bronzes, of imported Islamic glass, of fine Northern Song gold and silver vessels, and of Chinese lacquer wares of supremely simple design.

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So successful was the new Southern Guan ware that further long (‘dragon’) kilns were established a few years later at Hangzhou, on the other side of the hill from Laohudong, at a site called Jiaotanxia. The first of these was uncovered in 1956 and was 23.5 m long, while a larger structure at Jiaotanxia was excavated from October 1985 to January 1986 and was 40.6 m long (Yao Guifang 1989, 407).

Figure 2. Shard of imperial-quality Yue ware. Silongkou kilns, Zhejiang province, ca. 1130 – 1150 AD.
This larger kiln is now roofed-over and serves as the focus for the Guan Ware Kiln Museum in Hangzhou.

6. The Longquan connection
Soon after the establishment of the Hangzhou Jiaotanxia kiln, manufacture of a Guan-type ware was also initiated some 200 miles to the south of Hangzhou, in the Longquan region of the south-western Zhejiang province. Two kiln sites in particular are associated with the production of this provincial Guan ware - Dayao and Xikou, both near the market town of Longquan (Chou Jen et al. 1973, 153-5). Official planning rather than local enterprise should perhaps be suspected in the creation of the Longquan Guan ware, and in the sudden appearance of this advanced ceramic in this region. Indeed, compositional analysis can hardly distinguish the Longquan copies from the Hangzhou originals (Chen Xianqiu et al. 1986, 163-4, Tables 2-4).

Table 3. Compositions of di ware glazes, compared with average Yue ware and qingbai types (Sources used: Vandiver and Kingery 1986, 188 (SEM - EDA); Sundius and Steger 1963, 492 (analytical technique not reported); Wood et al. 2005, 194 (SEM - EDS)).

<table>
<thead>
<tr>
<th>Glaze Type</th>
<th>Na₂O</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>CaO</th>
<th>TiO₂</th>
<th>FeO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Di ware glaze Dayao</td>
<td>0.1</td>
<td>0.6</td>
<td>14.3</td>
<td>67.2</td>
<td>0.2</td>
<td>4.2</td>
<td>10.0</td>
<td>0.07</td>
<td>1.3</td>
</tr>
<tr>
<td>Di ware glaze Dayao</td>
<td>0.1</td>
<td>0.7</td>
<td>13.9</td>
<td>68.9</td>
<td>0.2</td>
<td>4.4</td>
<td>8.7</td>
<td>0.02</td>
<td>0.9</td>
</tr>
<tr>
<td>Di ware glaze Dayao</td>
<td>0.1</td>
<td>0.4</td>
<td>14.3</td>
<td>68.6</td>
<td>0.1</td>
<td>5.0</td>
<td>10.4</td>
<td>0.02</td>
<td>0.7</td>
</tr>
<tr>
<td>Di ware glaze Dayao</td>
<td>0.3</td>
<td>0.5</td>
<td>15.5</td>
<td>68.1</td>
<td>0.2</td>
<td>5.1</td>
<td>8.1</td>
<td>0.02</td>
<td>1.5</td>
</tr>
<tr>
<td>Di ware glaze Dayao</td>
<td>0.1</td>
<td>0.7</td>
<td>15.7</td>
<td>67.6</td>
<td>0.3</td>
<td>3.9</td>
<td>10.4</td>
<td>0.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Yue glaze av. Shanglinhu</td>
<td>0.9</td>
<td>2.4</td>
<td>13.2</td>
<td>61.3</td>
<td>1.2</td>
<td>1.7</td>
<td>15.2</td>
<td>0.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Qingbai glaze Jingdezhen</td>
<td>1.0</td>
<td>0.6</td>
<td>14.0</td>
<td>65.4</td>
<td>0.07</td>
<td>2.0</td>
<td>15.4</td>
<td>0.05</td>
<td>1.1</td>
</tr>
</tbody>
</table>
But why should a new Guan ware manufactory have been established so far from the capital? The answer may be that the region was chosen because wood-fuel was so abundant at Longquan and running short at Hangzhou, which was fast becoming one of the larger cities of the world, and also an important port and shipbuilding centre. There was also an established tradition for making fine Yue-type wares in the south-western Zhejiang province, so good ceramic skills were already in place (Vainker 1993, 37). Suitable raw materials for Guan ware manufacture must have been discovered there too — materials quite different from those then used in the local greenware tradition.

7. The appearance of di ware

Almost simultaneously with the appearance of Longquan Guan ware at the Dayao and Xikou kilns, another new ceramic type started to be produced in the Longquan district — one that may have been pioneered at the Longquan kilns themselves. This was di ware. This typology shared many of the forms and the thick, even, multi-layered bluish glazes of Hangzhou Guan ware, but used a pale grey porcellaneous body instead. Heavy crazing (an admired feature of true Guan ware) tended to be absent from di wares, and the glazes were invariably of the lime-alkali rather than the lime glaze type. This combination of a fine pale porcellaneous body, refined Guan-type forms, and thick, jade-like, un-crazed glazes, resulted in a ceramic of quite exceptional quality.

With regard to the time of its first appearance, Ren Shilong writes: “The picture is clear: ceramics with thin paste and thick glaze [i.e., di ware and ‘Longquan Guan ware’] first occurred in the Chunxi reign of the middle Southern Song period, but not earlier’ (Chunxi reign was 1174-1189) (Ren Shilong 1994, 37). Likewise, Jin Zhiwei and Bao Kanjie wrote: “... it can be concluded that a few delicate Longquan celadon porcelains have likely appeared in the royal palace of Southern Song dynasty during the late reign of the Emperor Song Xiazhong”, again during the Chunxi reign (Jin Zhiwei and Bao Kanjie 2005, 405).

On the basis of the above, we can trace the di ware glaze technology back to the Huрабao kilns at Yaozhou, in Shaanxi province, of the early 10th century — and then through the various Ru ware kilns that operated in the Henan province in the late 11th and early 12th centuries AD. Following the fall of the Northern Song dynasty in 1127, these important ceramic principles were transferred to south China, and to the Laohudong and Jiaotianxi Guan ware kilns at Hangzhou. From Hangzhou, the blue celadon technology was then transmitted to Longquan — both for glazing ‘Longquan Guan wares’ and also for the new di ware material (Fig. 4). Analysis shows the remarkable consistency that was achieved with this prestigious blue celadon glaze over some three hundred years of production (Table 1).

With the use of data from previous publications, it is now also possible to propose a provisional outline chronology for the history of Chinese blue celadon glazes of exceptional quality — a process that led eventually to the di-type celadon wares of the Longquan kilns (Table 2).

8. Titanium dioxide and the di ware glaze

The colour of the di ware glaze derives from dissolved ions of iron (mainly Fe$^{2+}$ with some Fe$^{3+}$) in the glaze matrix. However, such fine bluish tones are easily changed to green

<table>
<thead>
<tr>
<th>Place &amp; Date of manufacture</th>
<th>Na$_2$O</th>
<th>MgO</th>
<th>Al$_2$O$_3$</th>
<th>SiO$_2$</th>
<th>K$_2$O</th>
<th>CaO</th>
<th>Ti O$_2$</th>
<th>MnO</th>
<th>FeO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dayao late 12th C</td>
<td>0.2</td>
<td>0.24</td>
<td>22.7</td>
<td>69.0</td>
<td>4.7</td>
<td>0.04</td>
<td>0.2</td>
<td>0.04</td>
<td>2.8</td>
</tr>
<tr>
<td>Dayao late 12th/13th</td>
<td>0.2</td>
<td>0.26</td>
<td>22.3</td>
<td>69.8</td>
<td>4.2</td>
<td>0.06</td>
<td>0.2</td>
<td>0.03</td>
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</tr>
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<td>71.4</td>
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<td>0.2</td>
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</tr>
<tr>
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<td>0.18</td>
<td>21.2</td>
<td>70.6</td>
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<td>0.05</td>
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<td>0.25</td>
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Figure 4. Transfer south-east of blue celadon technology in China, 10th to 12th century AD. (Line marks the tectonic division between north and south China; see Wood 2000a).
Figure 5. Effect of adding titanium dioxide to a lime-alkali celadon glaze containing 1.5% iron oxide (far left), up to 0.8% TiO₂ (far right), in 0.1% increments. Reduction firing to 1250°C.

by a titanium dioxide content higher than 0.2% in the glaze’s overall composition (Fig. 5; Ishii Tsuneshi 1930, 357; see also Table 3 for typical titania levels in the glazes discussed).

9. Multi-layer glaze application

The colour of blue celadon glazes can be maximised by thickness. However, thick plastic glazes in their raw states tend to crack as they dry, and such cracks can lead to ‘crawling’ in firing — that is, bare patches appearing in the glaze surfaces. Applying the glaze as a series of thin layers can overcome this problem, particularly with higher alumina, and therefore more plastic, clay- or mica-rich glazes, such as those used on Guan wares and di ware. As many as four separate layers may be seen in a single thickness of a Laohudong Guan ware glaze, and the same technique was applied to both Longquan Guan ware and di wares (Sundius and Steger 1963, 430, Fig. 39; 438, Fig. 46).

Just how long this multi-layer glazing technique had been practised in China is difficult to say, but one can suspect its use on luxury celadon wares in north China before the technique was transferred south. In particular, a very fine, but broken and repaired, example of Ru ware in The British Museum was dismantled recently for restoration. This bowl has been identified as a likely candidate for the description ‘Northern Guan ware’, and its thick glaze and thin body appear very close indeed to the Guan wares that were made a few years later in south China (Krahl 1993; Wood 2007). Analysis indicated a northern composition for this British Museum bowl (Ian Freestone personal communication), and recent research has proposed Zhanggongxiang (one of the last Ru ware kiln sites in north China) as a likely site for its manufacture (Sun Xinmin 2006, 16-7).

10. Was the di ware glaze fluxed mainly by wood ash or by limestone?

As to the main glaze-flux used for di ware, the best indication for whether wood ash or limestone was the dominant flux is found in the P₂O₅ content of the glaze (Zhang Fukang 1986, 44). Southern greenware glazes tend to have average 1.0% P₂O₅, which is high, and suggests wood ash. In contrast, in most qingbai glazes, P₂O₅ levels average about 0.1%, which is low, and suggests limestone. Southern Song Dayao di glazes show phosphorous oxide levels of about 0.2%. These are low, but not entirely negligible, and thus a predominance of limestone, plus a minor amount of wood ash, may explain these P₂O₅ levels. The major glaze ingredient would have been a porcelain stone, much like the one used for the di ware body.

11. The di ware body

This proposed use of limestone in the di ware glaze has interesting parallels with qingbai technology, which, by the time that di ware first appeared, was already some two centuries old in southern China. Qingbai technology may therefore relate in turn to the use of porcelain stone as the main body material in di ware. However, the use of a rather ferruginous porcelain stone, or the mixture of porcelain stone with red clay, as proposed by Chou Jen et al. (1973), was unprecedented in the qingbai tradition, where purity was everything. There are some rare instances of white porcelain stone usage in the Longquan region during the Northern Song dynasty, but these are few and far between. Likewise, bluish celadon glazes appear occasionally on some rare Northern Song Longquan celadons with grey bodies - but the ‘di ware’ combination of the thick bluish lime-alkali glaze on a thin pale porcellaneous body seems to have been a major innovation of the late 12th century AD.

Perhaps a more likely source for porcelain stone usage in di ware might be found in Longquan Guan ware. As discussed above, di ware is contemporary with Longquan Guan ware, at interlinked with the northern composition of Longquan Guan wares — therefore relate in turn to the use of porcelain stone as the main body material in di ware. However, the use of a rather ferruginous porcelain stone, or the mixture of porcelain stone with red clay, as proposed by Chou Jen et al. (1973), was unprecedented in the qingbai tradition, where purity was everything. There are some rare instances of white porcelain stone usage in the Longquan region during the Northern Song dynasty, but these are few and far between. Likewise, bluish celadon glazes appear occasionally on some rare Northern Song Longquan celadons with grey bodies - but the ‘di ware’ combination of the thick bluish lime-alkali glaze on a thin pale porcellaneous body seems to have been a major innovation of the late 12th century AD.

Figure 6. Titanium dioxide levels in Chinese blue celadons, 10th-13th centuries AD (Analyses from Wood et al. 2004a, 225 (SEM-WDA); Zhu Wenli and Zhu Yufeng 2002, 448 (PIXE); Li Jiazhi et al. 2001, 35 (EPMA); Vandiver and Kingery 1986, 188 (SEM-EDA)).
which used a body made from a refined primary red clay, and a glaze that was probably a mixture of white porcelain stone with limestone and/or wood ash (Kerr and Wood 2004, 583–4). With Longquan di ware, the body is probably a naturally slightly ferruginous pale porcelain stone, or a white porcelain stone mixed with a small amount of refined primary red clay. Thus, two materials used for making Longquan Guan ware could have become the basis for the Longquan di ware body. This may be a coincidence, or it may be that di ware was developed through experience at Longquan with the new Longquan Guan ware raw materials.

12. After di ware

Di ware was produced in relatively small quantities, for a discerning market. A version with a greener glaze, but sharing the same superior craftsmanship, was devised in the 13th century. This in turn led to the mass-produced, thick-bodied, green-glazed material that became a huge commercial success with the establishment of the Mongol Yuan dynasty in the late 13th century (Ren Shilong 1994, 40). Hundreds of new ‘Longquan ware’ kilns sprang up in this region, with Dayao itself remaining an important production site well into the Ming dynasty period (Krahl 2004, 70–1).

13. Changes occurring in the Dayao body material from the late 12th to the 14th century AD

While recognisably the same material, the Dayao body gradually became richer in potassium and lower in iron and titanium oxides over the centuries — that is, whiter and slightly more vitreous. This could be explained by the use of deeper and less weathered porcelain stones and/or by the use of less red clay in the body recipes. This later Longquan material was made in colossal quantities and exported on an equally massive scale.

14. Summary and conclusion

Despite the obvious visual differences between the two wares, Jingdezhen porcelains and Longquan celadon wares are closely related technologically ‘beneath the skin’. Both used bodies based on micaceous porcelain stones, often with primary clay additions, and both used the advanced and stable lime-alkali style of high-temperature glaze. For much of the 14th century AD, the two kiln sites were practically matched ware-for-ware, although the huge dishes and vases produced at Longquan in the 14th century, measuring as much as a metre in diameter or height, did not appear at Jingdezhen until the 15th century AD.

However, when the origins of these body types and glaze types are considered, the reasons for their adoption seem rather different. For example, the use of kaolin at Jingdezhen was probably related to resource-depletion, and to the need to exploit reserves of non-kaolinised porcelain stone (Tite et al. 1984, 153). At Longquan, in contrast, the occasional additions of iron-rich primary clays to white porcelain stones was more likely to have occurred in the search for a visually harmonious body to use with the jade-like celadon glazes that were adopted there in the late 12th century, inspired by Guan ware. With regard to the glazes themselves, the development of underglaze blue painting at Jingdezhen meant that the fluid lime glazes that had been staples for qingbai wares for some three hundred years had to be replaced by the more viscous style of lime-alkali glaze, to prevent the blue painting from running at full heat. At Longquan, the use of the lime-alkali glaze can be traced back to the 10th century blue celadons of Yaozhou. This glaze then saw a complex train of succession on imperial-quality stonewares, before its eventual adoption at Longquan. In this case, lime-alkali glazes were adopted for the fine colours they gave with small amounts of iron oxide in solution, and for their firing stability when applied in successive layers to substantial thicknesses.

Thus, we see a pattern of parallel technological development at Jingdezhen and Longquan — but probably driven by rather different causes. In some ways, Jingdezhen can be seen as representing a simpler and more local technological history that was essentially southern, and unconnected with the history of imperial-quality north Chinese stoneware. In contrast, di ware can be regarded as the pinnacle of one major ceramic tradition in China and the beginning of another — namely the culmination of high-quality bluish celadon-making, initiated and largely developed in north China, and the start of large-scale Longquan celadon production, using local porcellaneous materials.

In the end though, the success of Jingdezhen blue and white ceramics led to the demise of the Longquan celadon industry. As the Jingdezhen kiln complex expanded in the 15th and 16th centuries, the manufacture of Longquan-type celadon ware declined through the effects of competition, and also following the withdrawal of official patronage (Krahl 1986, 55; Kerr and Wood 2004, 581). By the 17th century, the Longquan material was practically extinct — marking the decline and eventual collapse of one of the world’s most successful and productive ceramic traditions.

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