"Richō tōji no nanafushigi" [Seven wonders of Chosŏn ceramics, 1959]. *Zenshū* 6: 530-43.
"Richō yōmanroku" [Essay on Chosŏn ceramics, 1922]. *Zenshū* 6: 187-217
"Sekika ni tsuite" [Concerning red radicalisation, 1920]. *Zenshū* 1: 381-7.
"Tōjiki no bi" [Beauty of ceramics, 1921]. *Zenshū* 12: 3-26.
"Ushinawaren to suru ichi Chōsen kenchiku no tameni" [For a Chosŏn building on the verge of demolition, 1922]. *Zenshū* 6: 145-54.

Technological parallels between Chinese Yue wares and Korean celadons

Nigel Wood

The grey-green Yue wares of south China (made from the 4th to the 11th centuries AD) and the bluish-green Koryŏ celadons of south Korea (made from the 11th to the 14th centuries AD) are two of the most distinguished productions in the history of world ceramics. The Yue kilns provided some of the first Chinese stonewares to meet with Imperial approval, as well as establishing a domestic and export industry of unprecedented scale between the 9th and the 11th centuries AD. The development of Korean celadons owed a great deal to the Chinese Yue tradition in terms of forms and manufacturing methods; but Korean potters took the Yue style to new heights through their use of subtle bluish-green celadon glazes plus complex and ambitious designs.

These fine Korean celadon glazes, once described as showing as many colours and qualities as the sea itself, were often used over white and black inlaid patterns. The inlaid style of Korean celadon ware appears to have started production in the mid-12th century and flourished in the later Koryŏ Dynasty (918-1392). A more rustic version of the tradition continued well into the Chosŏn Dynasty (1392-1910), usually employing stamped rather than carved designs.

That significant historical and stylistic parallels exist between Yue wares and Korean celadons (particularly between the 9th to 11th centuries) has long been appreciated by students of Eastern art; but it is only recently that the technological relationships between Chinese Yue wares and Korean celadons have been properly investigated and understood. These new insights have come from four programmes of analytical research: carried out in Korea from 1981 (Lim 1986), at Oxford University from 1982 (Hatcher *et al.* 1985; Tite & Barnes 1992), at the Smithsonian Institution, Washington D.C. from 1986 (Vandiver 1989; Vandiver *et al.* 1989), and at Chung-Ang University in Seoul from 1991 (Choo 1994).

Taken as a whole, this detailed work has shown how closely related Chinese Yue wares and Korean celadons are in their essential body compositions and also in their general production technologies. It has also helped to explain the vital differences

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that exist between the glazes used in China and Korea for celadon wares. The present paper is intended as a resumé of this scientific work, beginning with a sketch of the historical and technical backgrounds to the two materials.

Yue wares

Of the two stoneware traditions (Yue and Koryŏ celadon), Yue ware is by far the older, with its technical roots reaching deep into China's Bronze Age, the Shang Dynasty (16-11th c. BC), making Yue wares direct successors to some of the world's oldest glazed stonewares. In developing and adding to the Yue tradition, Korean celadon potters were building upon an East Asian stoneware technology that—by the 10th century AD—was already at least 2000 years old.

Yue ware origins

The origin of glazed stoneware in China is a well-researched subject, particularly through the work of LI Jiazhi of the Shanghai Institute of Ceramics. Professor Li has studied the evolution of Chinese stonewares for some 40 years, paying particular attention to the wares of Zhejiang province in southern China, one of the birthplaces of Chinese high-fired ceramics. In recent papers, Li and his colleagues described some examples of southern Neolithic wares, south Chinese unglazed, stamped stonewares, and south Chinese glazed stonewares—which were made from essentially similar raw materials (Li 1986; Li *et al.* 1989; Li *et al.* 1992). Many of these late Neolithic and early Bronze Age ceramics were fired and cooled in reducing atmospheres, which gave a cool greyish cast to the wares. Reduction firing may well have been adopted by Chinese potters to improve the fired strength of their wares through the fluxing effects of ferrous oxide (FeO) above about 900°C—an approach still used in China for the production of grey bricks and roof-tiles.

Following these developments, unglazed grey stoneware became south China's main Bronze Age stoneware type, with some examples showing thin glossy patches where fluxes present in fly-ash (produced by wood-firing) reacted with the clay surface at high temperatures to provide natural glaze effects. From these accidental patchy glazes, it would have been a short step for south Chinese potters to begin applying wood ashes direct to their wares before firing in order to achieve controlled and deliberate ash-glaze coatings (Zhang 1986).

This deliberate application of wood ash glazes occurred quite early in the Shang Dynasty; and a number of early Shang stonewares, beaten with cord-wound paddles and glazed thinly and evenly outside, can be seen in Chinese collections such as that of the Shanghai Museum. Sherds of similar wares have been found at Shang sites at Jiaoshan and Wucheng (Jiangxi province), Yixing (Jiangsu province) and at Jiangshan (Zhejiang province) (Li *et al.* 1992). Even so, despite the potential usefulness of this technology, fully-glazed Shang stonewares seem to have accounted for only a minute fraction of Shang ceramic production (Figure 1).

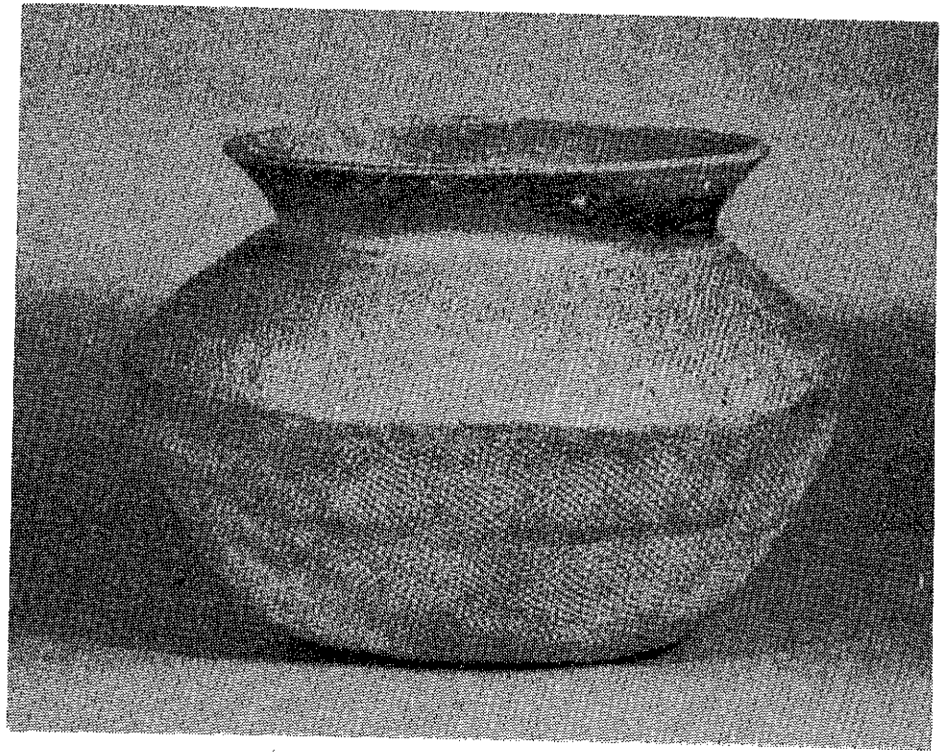

Figure 1 *Stoneware jar, coiled and beaten with a textured paddle and bearing a thin olive-green ash-rich stoneware glaze.*
South China, Shang Dynasty (*ca.* 1500-1050 BC); diameter 8"

Most Shang glazed stonewares have been found at southern sites, with only some 0.2% of the total having been excavated in north China (Luo *et al.* 1992; Deng and Li 1992). This significant disparity has led to intense debate on the provenance of these northern finds. On good compositional grounds, Luo believes that these early glazed stonewares were actually made in south China and then transported to the developing fortified cities of the Yellow River area. This opinion is based on the existence of a very sharp geological divide that runs just north of the Huai river and which crosses China from west to east (Tregear 1980).

This important natural division is known to geographers as the Nanshan Qinling divide, named after the Nanshan and Qinling hill systems that make up the more westerly reaches of the feature. North of this divide, the main high-firing ceramic raw materials are refractory and rather ancient sedimentary stoneware and porcelain clays which are often associated with north China's coal fields. South of the divide, weathered igneous rocks and the silty downwashes from similar materials provided the main materials for southern stoneware and, much later, for southern porcelain.

North Chinese high-firing materials tend to be rich in true clays (mainly kaolinite) and consequently high in alumina, low in silica and low in potassia. These local northern stonewares were little-used for glazed stoneware production before the late 5th century AD. By contrast, the southern stoneware and porcelain materials consist largely of quartz, micas and some feldspars, with relatively low true-clay contents. As a result of these mineralogical differences, southern materials show high silica, low alumina and high potassia percentages when analysed—exactly opposite the characteristics of their northern counterparts (Guo 1987; Guo *et al.* 1980; Guo & Li 1986; Sundius & Steger 1963).

Although glazed stonewares were a significant south Chinese innovation, they remained rare during the later Bronze Age, when unglazed grey, stamped stonewares continued as the main high-fired products. The few glazed stonewares that have survived from this time include small thrown bowls, jars, dishes and ewers with green and brown ash glazes, made near Tunxi in southern Anhui province in the late Western Zhou period (11th c. BC-770 BC). In the Spring & Autumn period (770-476 BC), fairly large coiled-and-beaten glazed jars with well-fitting covers, and stamped and combed designs, were made at kilns in Zhejiang and Jiangsu provinces (Yang *et al.* 1985). In the Warring States period (475-221 BC), some thinly-glazed thrown vessels, imitating round bronze forms, were made in Zhejiang province—apparently for burial use. These various wares supplied a tenuous continuity for high-fired glazes in south China through a time when unglazed grey wares remained the dominant stoneware type.

Somewhat later, in the Western and Eastern Han Dynasties (206 BC-AD 220), large thrown stoneware jars and covered boxes of a more utilitarian style were made in Jiangsu and Zhejiang provinces. These impressive bronze-derived forms (Figure 2) have mottled ash glazes applied to their upper bodies, shoulders and lids—apparently achieved by sifting wood-ash over the objects before firing (Ayers *et al.* 1988). The kiln sites responsible for these so-called 'proto-porcelain' wares seem to have operated in areas that were later famous for their Yue ware productions (Sato 1981).

By the 3rd and 4th centuries AD, wheel-thrown stonewares with fine grey-green all-over clay and ash glazes were being made on a considerable scale in Jiangsu and Zhejiang provinces in south China. From these fully glazed stonewares developed south China's famous Yue wares. These took their name from a district between Hangzhou, Shaoxing and Ningbo that was known as the state of Yue as early as the Spring and Autumn periods (770-476 BC). This district (in northern Zhejiang) later became the prime producing area for the grey-green glazed stonewares known as Yue wares, particularly during the later Tang Dynasty (AD 618-907). The term 'Yue ware' is often used more generally today to describe the huge range of grey-green stonewares that were made in many provinces of southern China from about the 4th to the 11th centuries AD (Zhu 1989).

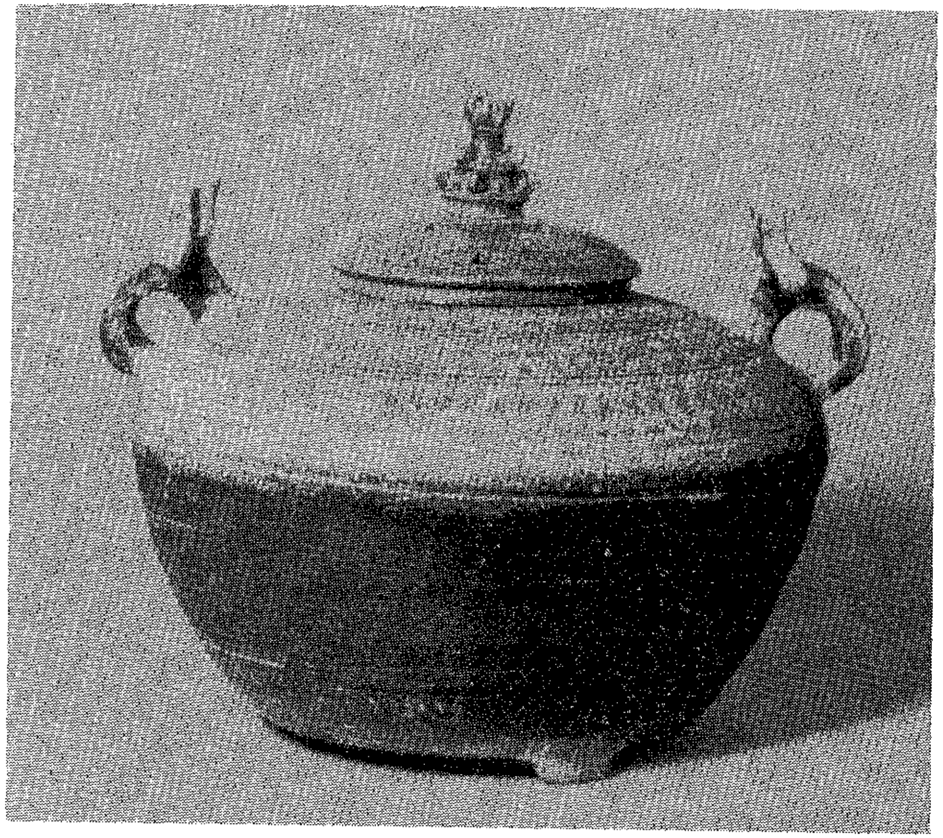

Figure 2 *Glazed stoneware covered jar with three small feet and two large handles, made in the form of a bronze* pou. *[The cover and bowl of this example may not have originally belonged together.] Probably glazed by sifted wood-ash, or by a sifted ash-clay mixture.*
3rd-4th c. BC, northern Zhejiang or southern Jiangsu; height 10.5"

Yue ware technology

Three technical principles above all were responsible for the success of the south Chinese Yue ware industries: 1) the presence in south China of abundant deposits of siliceous and flux-rich stoneware materials that were easily matured into tough stoneware bodies, as described above; 2) an efficient kiln design known as the *long* kiln; and 3) a glaze-making technique that mixed wood-ashes with body-clays to create grey-green stoneware glazes of fine technical quality (Figure 3).

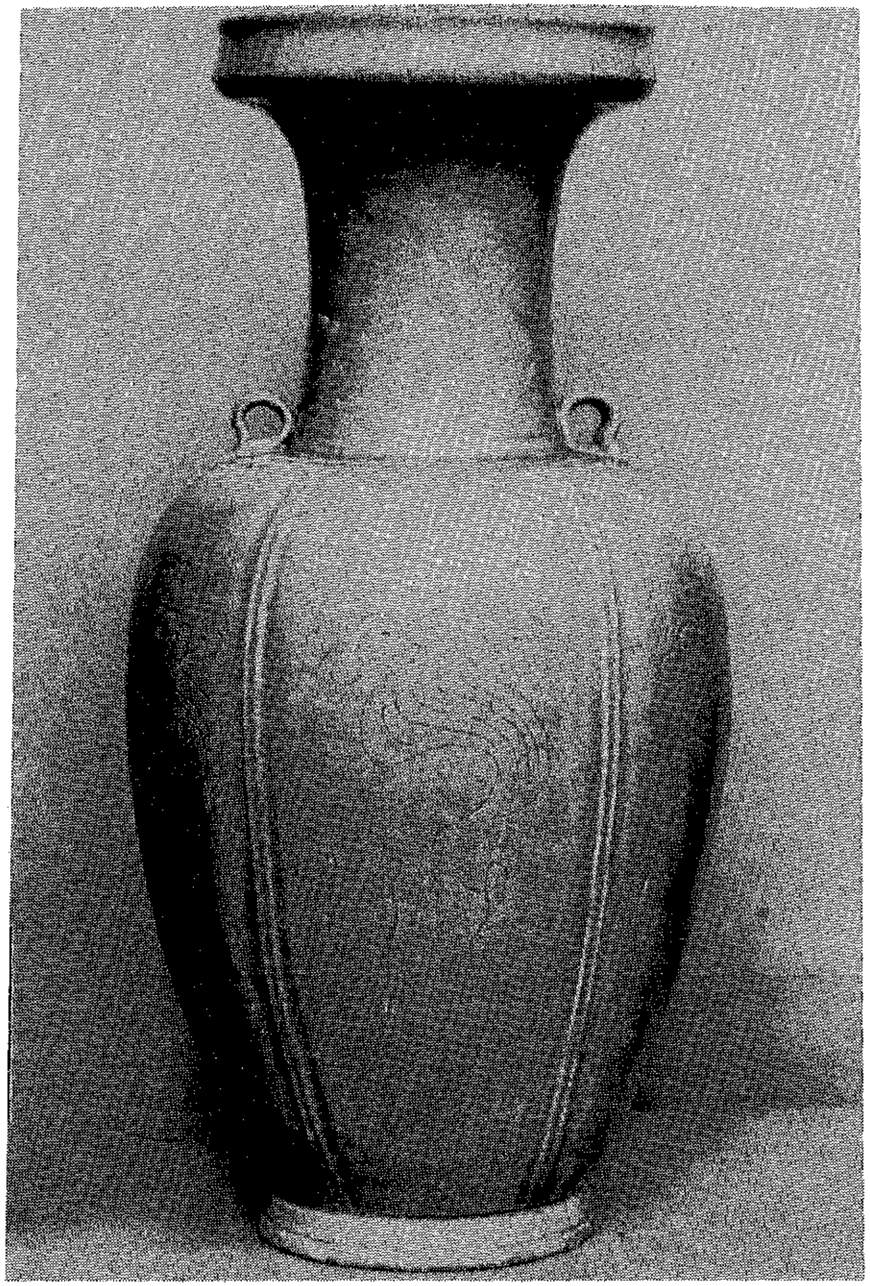

Figure 3 *Greenish-grey glazed stoneware vase, with the body divided into six shallow lobes and engraved with cloud designs.*

Late Yue ware or early Longquan ware, Zhejiang province; early 10th c. AD, height 12.5"

Yue ware kiln design

The *long* ('dragon') kiln principle, developed in south China in the Warring States period (485-321 BC), was essentially a short tunnel built up a low slope. Its firebox was at the bottom of the tunnel, while the top of the tunnel narrowed somewhat and served as the kiln's exit flue (Lao & Ye 1986). The wares were placed on short thrown columns set on the kiln's floor, which was either stepped or covered in a layer of quartz grit or sand. The earliest *long* kilns were tunnelled or 'cut and covered' into hillsides; they were only a few metres long and about one metre wide inside. They were packed and unpacked by crawling through the firebox end and into the excavated space. *Long* kilns were fired mainly with brushwood and reeds, although some later south Chinese *long* kilns used small amounts of coal as a supplementary fuel (Bureau of Foreign Trade 1933).

Long kilns are efficient because the flame-speed is slowed by forcing the combustion gases to follow a near-horizontal flame-path. This slower flame-speed meant more effective transfer of combustion energy to the wares, and it allowed high kiln temperatures to be achieved and sustained more easily than in the earlier updraught designs.

By the 3rd century BC, the Chinese *long* kiln had been improved through the addition of side-stoking ports along the upper part of the tunnel's length. These allowed fuel to be pushed into the kiln chamber itself where it burned fiercely amongst the wares, compensating for the fall-off in heat inevitable in those parts of the kiln chamber furthest from the main firebox. This 'stretched' version of the *long* kiln was later built from brick, with doorways set into the kilns' sides to make setting and drawing of the wares less awkward. These more advanced *long* kilns often ended with exit flues built as open brickwork chequers, protected by a low brick wall.

Soon a *long* kiln-firing regime was established in southern China whereby the lower part of the kiln was brought to full heat by stoking its main firebox, which was then bricked up. Side stoking then took over at the lowest port, and the full heat was gradually moved up the entire length of the kiln by the side-stoking of successive ports. By allowing air into the kiln some distance before the current stoking-port, the combustion air was pre-heated by passing over the cooling wares. This use of very hot air to burn the side-stoked fuel vastly improved combustion efficiency, allowing high kiln temperatures to be achieved rapidly with a minimal use of fuel. This principle of side-stoking made any length of *long* kiln feasible, and the design reached its zenith in the Longquan district of Zhejiang in the Southern Song Dynasty (AD 1127-1279), when *long* kilns approaching 100 metres in length were constructed (Zhou *et al.* 1973). The technique of side-stoking caused fairly rapid cooling of the wares; a firing time of 24 hours followed by a cooling period of 24 hours was not uncommon with smaller versions of the design. Such kilns are still abundant in the countryside of southern China.

At the premier Yue ware kiln-complex of Shanglinhu (Shanglin Lake) in northern Zhejiang province, which operated from the 4th to 11th centuries AD, the remains of some 106 *long* kilns can still be traced on the lightly-wooded slopes around the lake's perimeter. The longest of the Shanglinhu kilns was about 40 metres and was capable of firing thousands of pieces in a single setting. From the 9th century onwards, many of these wares were sent for export from the nearby port of Ningbo, whence they took a 5000-mile sea route to East Africa and the Near East, *via* Sri Lanka, where quantites of Yue wares have been found. Other export destinations for Chinese Yue wares in the 9th-11th centuries were Japan, Korea and the Philippines.

Yue ware glazes

As stated above, the third essential principle for the success of Yue ware technology was an approach to glaze-making that combined wood ashes with the same materials as were used for the bodies of vessels (Li *et al.* 1989). The two materials were mixed with water to make a creamy suspension; they were then applied to the wares by dipping, pouring or brushing.

Yue ware ash glazes exploited a chemical phenomenon now know as a 'eutectic mixture'—that is, a particularly fusible combination of two or more materials (Gr. *eutektos*: 'ideal-melting'). The Yue-type glaze compositions that resulted from this balanced mixture are known as 'lime glazes' because calcium oxide (loosely known as lime) acts as the primary glaze-flux.[1]

The chemical foundation of the Yue ware glaze is a mixture of silica, alumina and calcia in roughly eutectic balance. Individually, these three oxides are outstandingly infusible: silica (silicon dioxide, SiO_2) melts at 1713°C, alumina (aluminium oxide, Al_2O_3) at 2050°C, and calcia (calcium oxide, CaO) at 2572°C. However, in the correct proportions, a mixture of all three oxides will begin to melt into a glass or glaze at about 1170°C and will provide a good 'lime glaze' at another 20°C or so above this temperature (1190°C). According to Singer & German (1978), the proportions of this valuable eutectic mixture are:

62% silica + 14.75% alumina + 23.25% calcia

The ratios of silica to alumina in south Chinese stoneware clays tend to be similar to those in the eutectic mixture given above (about 4:1 by weight percent), so that all that was needed to make glazes from southern stoneware clays was a concentrated source of calcium oxide. This was easily supplied by wood ash (a rich source of calcium compounds) or, in later south Chinese glazes, by limestone, which is practically pure calcium carbonate ($CaCO_3$). Both wood ash and limestone break down to calcia (CaO) in the kiln at about 800°C, with a consequent loss of carbon dioxide (CO_2).

[1] A flux is a material that melts the glass-forming base of a glaze mixture, usually silicon dioxide.

Judging from the minor elements present in Yue ware glazes—mainly manganous oxide (MnO) and phosphorus pentoxide (P_2O_5), wood ashes seem to have been their main source of calcia. Unlike wood ashes, oxides of manganese and phosphorus are not found in Yue clays or in limestones to any extent, so they can be discounted as significant suppliers of MnO and P_2O_5 to the Yue glazes.

This use of wood ash/clay mixtures seems logical in view of the history of glazes stoneware in south China, and a mixture of the Yue ware body clay with about 30-40% wood ash would account for most analyses of Yue glazes so far published (Table 1).

Table 1 *Yue ware body and glaze analyses.*
(compiled from Guo *et al.* 1980; British Museum 1994, unpublished data)

compos.	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O	MnO
body	75.4	17.7	0.8	2.4	0.3	0.6	3.0	0.5	---	.03
body	77.0	15.8	1.0	3.2	0.3	0.6	2.6	1.0	0.1	0.03
body	76.6	16.1	0.9	1.6	0.2	0.5	3.0	0.9	---	0.01
glaze	60.9	12.1	0.7	3.0	16.5	3.0	1.4	0.8	1.6	0.4
glaze	57.9	13.7	0.6	1.7	19.7	2.4	2.0	0.7	0.9	0.9
glaze	57.4	12.5	0.8	1.8	20.3	3.0	1.3	0.9	1.5	0.4
body*	60.6	12.7	0.8	2.7	19.0	0.8	2.1	0.8	1.8	0.4

*experimental mixture of wood ash with siliceous clay in 65/35 proportions, made by the author and analysed at the British Museum, 1994.

The 1170°C lime eutectic itself provides a nearly colourless glaze, but the typical grey-green colours seen in Yue glazes derive from the iron and titanium oxides (FeO, TiO_2) that they contain; these were supplied mainly by the clay components of the original glaze recipes. Yue glazes were fired in reducing (slightly smoky) kiln atmospheres that were probably survivals of the reducing atmospheres already used for centuries in southern China for firing grey earthenwares and greyish stamped stonewares. Under reducing conditions, iron oxide would provide a bluish-green colour in the quantities found in Yue glazes, but this is modified to a yellower grey-green in most Yue glazes by their relatively high titania contents (0.7-0.9% TiO_2).

Chinese celadon glazes

Bluish-green celadon glazes are usually regarded as a major Korean innovation, but there do exist a few rare examples of Chinese stonewares with bluish-green, iron-coloured glazes, made in both the north and south of China in the 9th and early 10th centuries. These Chinese wares seem to anticipate the Koryŏ principle of applying bluish glazes to grey stoneware bodies.

One example is a small bottle, described as being Tang Yue ware, that is on display in the Palace Museum, Beijing. This piece has a rather experimental bottle form with an almost spherical body and tall cylindrical neck—a style that was later used successfully for some Koryŏ inlaid wares. This bottle shows a fine greyish-blue glaze that could easily be mistaken for a Korean celadon. It is hard to see how such a glaze could have been produced with traditional Yue-ware glaze materials, so it may have used some low-titania rocky ingredient in its original glaze composition.

Rather glassy bluish celadons, with colours reminiscent of some Koryŏ wares, have also been found at the Yaozhou kiln-complex in Shaanxi province (Liu 1992), and these stonewares are dated to the Five Dynasties period (907-960). These very rare 10th-century bluish Yaozhou glazes have yet to be analysed and their colours explained. There is also a Chinese tradition for an Imperial stoneware, made in the reign of Chai Shizong (r. 954-959), and known as Chai ware. No examples have been found, but the Chai kilns are thought to have operated in Zhengzhou, Henan province. Chai ware had a glaze that early Ming writers compared to the "colour of the sky after rain," a description that was later applied to the bluish-green Imperial Ru wares of the late 11th to early 12th centuries.

Ru wares have been analysed and shown to have low-titania lime-glazes which were coloured with small amounts of iron oxide and applied to greyish stoneware clays. These glazing principles were continued by the Imperial Guan wares of Zhejiang province, made in the late 12th and 13th centuries (Guo & Li 1986; Guo 1987). Bluish celadon wares therefore enjoyed unusual prestige, and this admiration was later extended among Chinese connoisseurs to the Koryŏ wares themselves.

Finally, and perhaps more relevant to the Korean celadons, are some fine bluish-glazed late Yue-type wares recently excavated at the ancient Yue kiln site of Ningbo in northern Zhejiang. These have glazes very similar in colour to Koryŏ celadons, and their style suggests an 11-12th century date (R. Krahl, pers. comm. 1992). Ningbo was the main port of dispatch for Yue wares destined for Korea.

Korean celadons

Geology and history

The main Korean celadon-producing sites were in the coastal areas to the west of the Korean peninsula, and reference to a map of East Asia shows most Koryŏ celadon kilns to be on the same parallels as the great ceramics-producing centres of north China, found in Henan, Shaanxi and Shandong provinces (Figure 4). These northern provinces were the homes of such famous celadon wares as Yaozhou, Linru and Ru-yao. Chinese potters in these areas exploited the clay-rich stoneware raw materials, described towards the start of this paper, that were often associated with the extensive coal fields of northern China.

Given that most Korean celadon kilns are found on the same geographical parallels as the celadon sites of north China, it is something of a surprise to find that Korean celadon clays are quite different from those used for northern Chinese ceramics. Korean celadon clays are of the low-clay, quartz-rich and high-potassia

types and are virtually identical in their compositions to the Yue ware bodies made some hundreds of miles to the southwest of Korea in northern Zhejiang (Table 2).

Table 2 *Korean celadon body analyses.*
(compiled from the Oxford analyses; Lim 1986; Choo 1994)

compos.	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	MnO
sample a	76.0	17.0	0.8	2.1	0.3	0.5	2.5	0.7	---	0.01
sample b	69.5	22.7	0.7	2.5	0.3	0.5	3.2	0.5	---	0.02
sample c	73.0	17.5	0.9	2.8	0.2	0.7	2.6	0.8	tr.	---
sample d	73.0	18.0	1.2	2.5	0.5	0.5	3.4	0.9	---	---

The explanation for this apparent paradox is that the landforms that underlie the provinces of southern Jiangsu and northern Zhejiang have a general southwesterly/northeasterly bias. These south Chinese igneous rocks disappear under the East China and Yellow Seas, to reappear as the landscape of south Korea, some 300-400 miles to the northeast of Zhejiang. In fact, if the Nanshan-Qinling divide were projected to include Korea, virtually the whole Korean peninsula would be found south of the divide. This vital relationship with the landforms of south China was summarized by the geographer Albert Kolb (1971: 251):

> ...the axis of south China's mountain system...can be traced from Canton to the south of Ningbo....This axis is not a mountain range in the ordinary sense but consists of long stretches of isolated massifs, ridges and crests, irregular areas of rugged heights rarely reaching 1899 m.
>
> This zone, marking an ancient anticlinal ridge...aligned from north east to south west, can be grouped with the Chusan [Ryūkyū] archipelago, the island of Quelpart [Cheju-do] and southern Korea as a single tectonic region.

Korean celadons and south Chinese Yue wares, therefore, share a common underlying geology, with the development of stoneware in Korea tending to follow a very similar path to that seen in south China—although at least 2000 years separate the beginnings of the two high-fired traditions.

Recent research at Oxford (Tite & Barnes 1992) has shown that Korean hand-built earthenwares were made from iron-bearing siliceous clays. Experimentation during the 1st to 6th centuries AD led to gradual firing at higher and higher kiln temperatures until some of the earthenwares were transformed into true stonewares towards the end of this period (Figure 5). Nearly all the body analyses of Korean earthenwares, made for the Oxford study, have direct parallels in published analyses of later southern Chinese glazed stonewares, such as those from Sichuan, Hunan, Zhejiang and Jiangxi provinces (Guo *et al.* 1980). This suggests that most of the Korean earthware clays, analysed at Oxford, were potential stoneware materials.

By the Unified Silla period (AD 668-935), thrown stonewares—fired in reducing atmospheres and often showing large perforations in their thrown feet and covers—

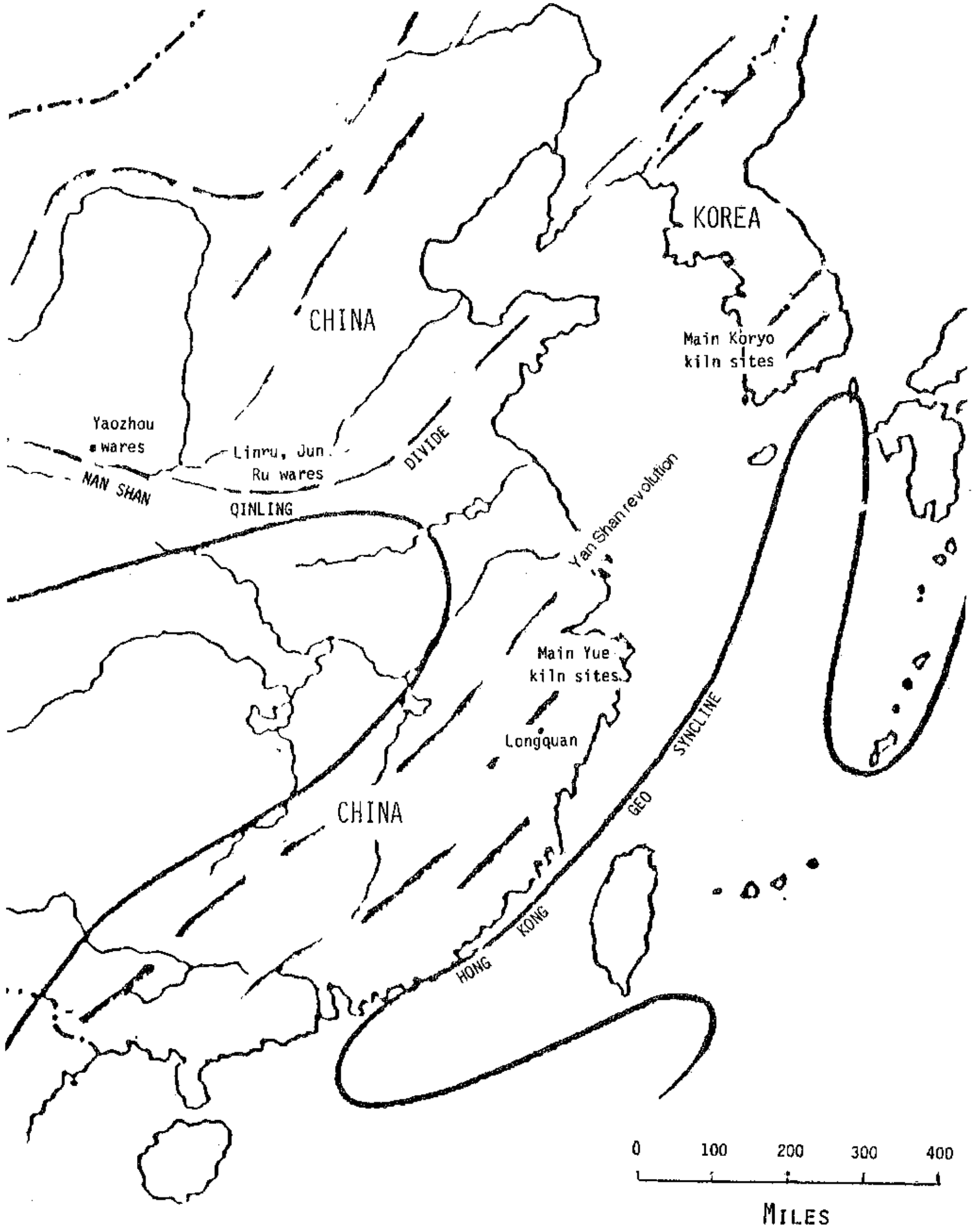

Figure 4 *Geological map showing direction of Yan Shan revolution (Upper Jurassic) geology as continuous between the areas of Yue and Koryŏ kiln production.* (after Tregear 1980, fig. 2D)

were being made in Korea. From about 600 to 850, reduction-fired thrown ceramics, decorated with repeating bands of stamped ornament, had become part of the Korean potters' repertoire. By the late 10th century, true celadon wares with grey-green glazes were being made at kiln sites in southern Korea (Vandiver 1989). And by the early 11th century, the familiar blue-green celadon glazes, for which Korean ceramics later became so famous, were beginning to appear (Choo 1984).

Figure 5 *Grey-brown covered dish with a tall foot; near-stoneware with traces of natural wood-ash glaze (kiln-gloss).*
Korean, Unified Silla period (668-935 AD); height 7.25", width 5.5"

Celadon glaze qualities

Once established, fine Korean celadon glazes changed little in essential composition for hundreds of years. Like Yue glazes, Korean celadons are lime glazes, but they seem even closer than Yue glazes to the 'ideal' silica-alumina-lime eutectic mixture. However, where Koryŏ celadons differ markedly from Yue glazes is in their general levels of colouring oxides—particularly the oxides of iron and titanium (Table 3).

Table 3 *Koryŏ celadons and Chinese Yue ware glazes compared.* (compiled from Vandiver 1989; Lim 1986; Choo 1994)

compos.	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	MnO
Yue	58.9	12.7	0.7	2.4	19.5	1.9	2.2	0.8	0.8	0.2
Yue	63.7	11.7	0.6	2.2	15.1	2.7	1.6	0.8	1.6	0.4
Yue	57.4	12.5	0.8	1.8	20.3	3.0	1.3	0.9	0.2	0.3
Koryŏ	57.6	12.4	0.1	2.1	17.7	4.2	2.8	0.7	0.2	0.3
Koryŏ	58.1	13.9	0.2	1.4	19.9	1.8	2.9	0.5	0.9	0.4
Koryŏ*	**60**	**12**	**0.1**	**1.0**	**19.0**	**2.5**	**2.5**	**0.75**	**0.8**	**0.5**

* mean of Koryŏ celadon measures

Above all, the levels of titanium dioxide are responsible for the celebrated Koryŏ glaze-colour, as they are low enough to allow true iron-blue colours to develop in the Korean glazes. As mentioned above, the natural colour of FeO dissolved in a lime glaze (Fe++) is a watery blue, which soon modifies to green with small additions of titanium dioxide (>0.2%) (Ishii 1930). Another feature of Korean celadon glazes (compared with Chinese Yue glazes) is their relatively high potassium oxide (K_2O) contents—averaging about 3% K_2O compared to about 2% K_2O in the Yue glazes. A further important difference is that Koryŏ glazes are generally lower in iron oxides.

Raw materials for Koryŏ celadons

A possible explanation for all these features (low titania, higher potassia, lower iron) might be that the Koryŏ potters used porcelain stones rather than body-clays in their celadon glaze recipes. Porcelain stones are low titania, high potassia, low iron materials, but otherwise they are similar to Korean and South Chinese stoneware clays in their silica and alumina levels.

It may be significant that white-firing quartz-mica porcelain stones, of the well-weathered type, were often found in south China in association with stoneware raw materials. This was a convenient situation that led many important kiln-complexes such as Jingdezhen in Jiangxi province, to convert from stoneware to porcelain-making in the 10th to 11th century AD.

Given the strong geological parallels that exist between south China and Korea, it seems likely that porcelain stones of this same type occurred nearby many Korean kiln sites specializing in early celadon wares (Figure 6). Indeed, the production of white porcelain itself in Korea is almost as ancient as that of its bluish-green celadon wares, although the porcelain industry operated on a much smaller scale than in China. Some support for the idea that Koryŏ potters were able to use porcelain stones in their celadon glazes comes from two sources (see also Table 4). First, Choo has published a single analysis of an 11th-century Korean white porcelain that has a composition typical of a 'single rock' porcelain, such as Jingdezhen *yingqing* ware (Choo 1995). There is also an interesting analysis of a rock collected from a 12th-century Korean celadon kiln site, Sadang-ri. This rock consisted of compacted volcanic ash, known as tuff, as did many Chinese porcelain stones of the Jingdezhen type (Lee, 1989; Wood 1986; Nikulina & Taraeva 1959).

Further important finds from the Sadang-ri site were quantities of both wood ash and shell. Shell consists almost entirely of calcium carbonate, suggesting that the material may well have served as a useful supplementary source of calcia in some Koryŏ celadon glazes.

Table 4 *Comparison of Jingdezhen* yingqing *ware, Korean porcelain and Sadang-ri tuff.* (compiled from Wood 1986; Choo 1995; and Lim 1986)

compos.	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O
yingqing	77.8	16.2	0.07	0.6	0.8	0.2	3.1	1.0
Koryŏ	73.6	17.6	0.1	1.8	0.3	0.4	5.8	0.4
Sadang-ri	71.6	17.5	0.2	2.7	0.5	0.3	4.6	2.5

However, oxide analyses of Koryŏ celadon glazes (particularly when viewed from their phosphorus and manganese contents) tend to suggest that mixtures of porcelain stone with about 30-50% of wood ash were the most typical glaze recipes used by the Korean celadon potters. This mixture can provide a near-eutectic oxide balance of the lime-glaze type, giving stable and transparent compositions that accommodate well to variations in firing-temperature and kiln-atmosphere. With such a successful glaze-base, it is perhaps not surprising to discover that this same celadon glaze remained in use in Korea for many hundreds of years (Vandiver 1989).

In China, by contrast, Yue-type wares developed gradually into the Longquan celadon tradition between the 12th and 13th centuries; it exploited the more unctuous and jade-like qualities that were possible with lime-alkali glazes. This process involved the development of celadon kilns some two hundred miles to the south of Shanglinhu in order to exploit the light-firing porcelain stones so abundant in southern Zhejiang but rarer in the north of the province. The Longquan lime-alkali glazes appear to have been made from porcelain stone/limestone mixtures in about 8.5:1.5 to 8:2 proportions (Wood 1978) (Figure 7).

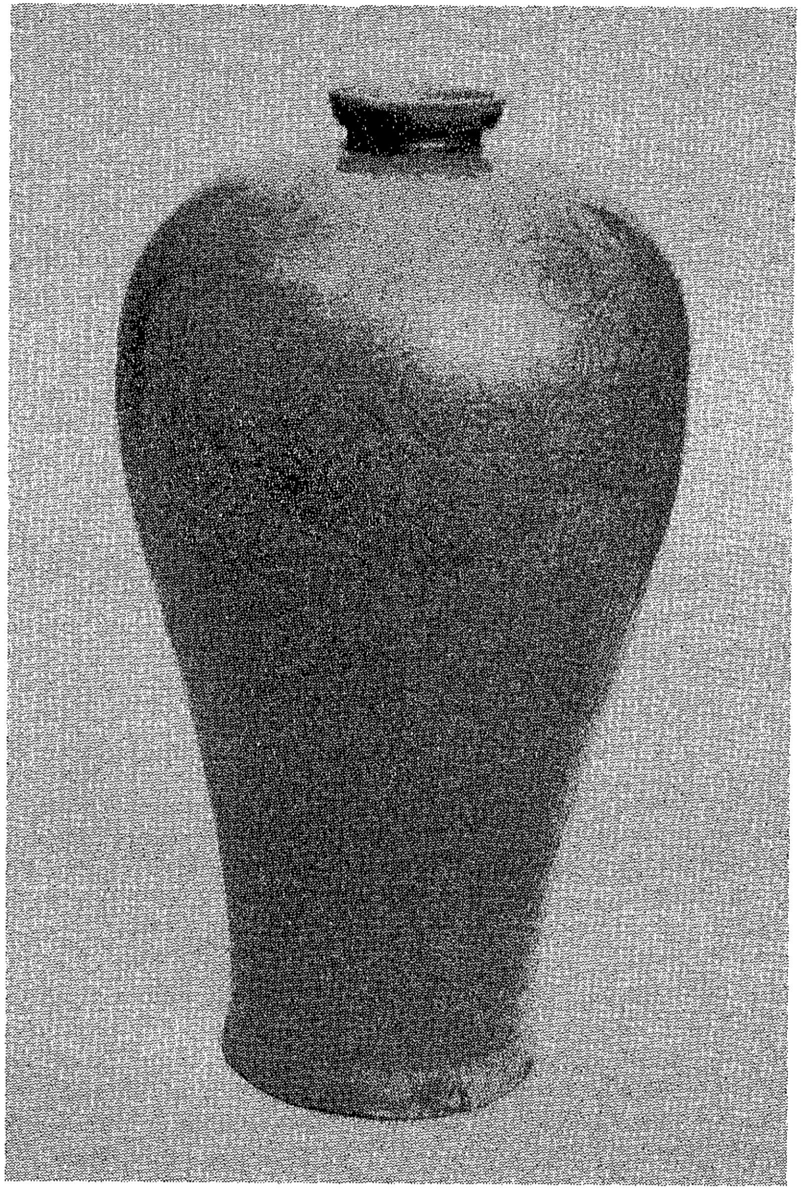

Figure 6 *Celadon* maebyŏng *vase with lotus designs engraved into the stoneware body.* Korean, probably 12th c.; height 13.4"

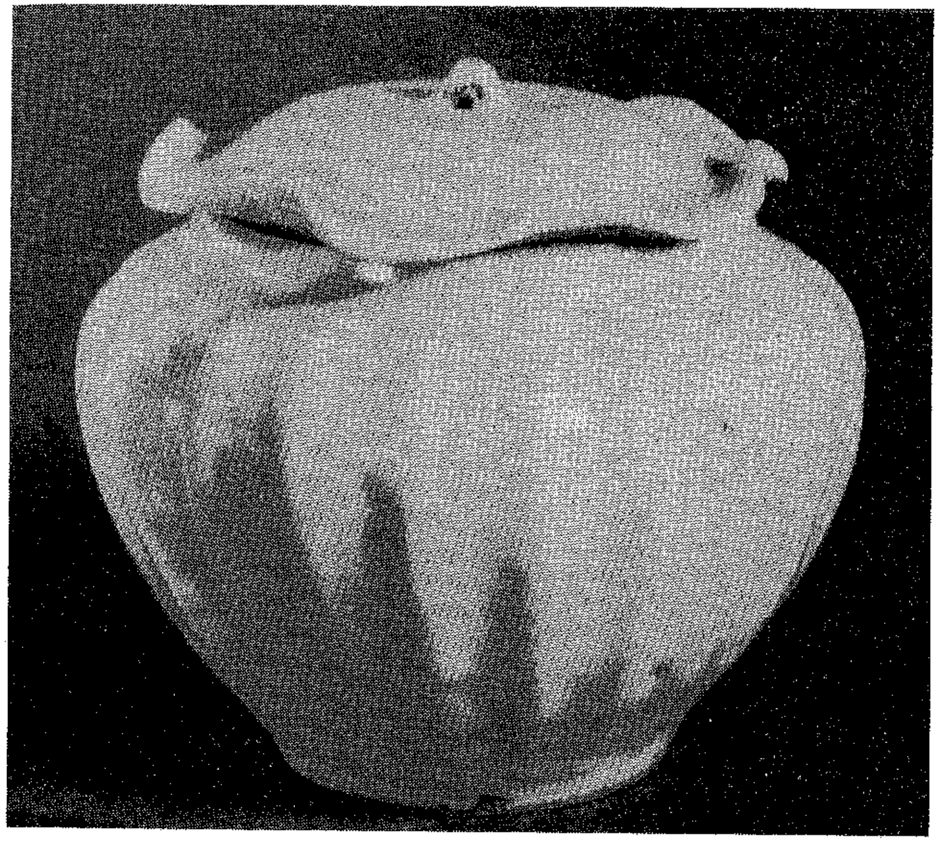

Figure 7 *Longquan covered jar with a fine bluish lime-alkali* kinuta*-style celadon glaze.* Chinese, 12th c. AD; height (with cover) *ca.* 5"

Korean kiln technology

Barnes (1993) has proposed that small kilns of essentially *long* design were in use in Korea from at least the 3rd century AD for firing earthenwares and that this design was probably introduced to Korea from China in the late Eastern Han Dynasty (AD 25-220). *Long* kilns of generally small scale (5-17 metres long and about a metre wide inside), but with facilities for side-stoking, later became the standard kilns used by the Koryŏ celadon industry. These 'small' *long* kilns allowed faster firing and cooling rates than were possible with most Chinese Yue wares, which made the Korean glazes less likely to develop anorthite crystals in the early stages of cooling (Vandiver 1989; Vandiver *et al.* 1989). Koryŏ celadons are consequently more transparent than Yue ware glazes, a characteristic that contributed to the notable success of the Korean inlaid stoneware tradition.

Li Jiazhi has proposed that the firing temperatures used for Shanglinhu Yue wares "averaged 1100°C" (Li *et al.* 1989), and Vandiver puts the firing temperatures for Koryŏ celadons to between 1100 and 1150°C. These are low temperatures for wares with true stoneware glazes and are in the 'high earthenware' rather than the 'low stoneware' range. Recent reconstructions of Yue ware and Koryŏ celadon glazes, made by the author in 1994, would not melt much below 1200°C and were not overfired at 1230°C; thus the original firing temperature may be an aspect of Koryŏ celadon technology that needs further study.

Koryŏ slip-painted wares

Lime glazes of the Yue and Koryŏ types were unsuitable for use with underglaze painted decoration with concentrated oxide pigments, as these colouring oxides tended to diffuse into the glazes during firing—as seen on the early Yue 'iron spotted' wares. The more viscous style of lime-alkali glaze had to be developed in China before underglaze painting with oxide-rich pigments (particularly cobalt blue) could become important in East Asian ceramics.

Nontheless, underglaze *slip* decoration is possible with lime glazes because the high-temperature solubility of the oxide pigment is then inhibited by the substantial presence of clay in the pigment mixture. Even so, Korean potters tended to fire most of their slip painted wares in oxidizing to neutral atmospheres, which gave the wares a yellowish or amber cast. The reasons for these oxidized firings are still obscure: oxidation may have been useful in preventing the iron oxide from taking its lowest ferrous form (FeO), where it could act as a powerful flux. In its ferric (Fe_2O_3) and ferroso-ferric (Fe_3O_4) states, iron oxide is rather inert and will not react strongly with the glaze above. There is also the aesthetic consideration that well-reduced greenish blue celadons, with underlying black slips, show a rather stark colour contrast, while amber glazes and dark brown slips present a more harmonious appearance (Figure 8).

Using these two approaches (clay-rich iron-bearing slips and oxidizing to neutral firings), rather broad slip-painted designs beneath lime-rich celadon glazes became possible. The technique was used successfully at a number of Korean celadon kiln-sites.

The inlay technique

The greatest innovation of the Koryŏ celadon tradition was the use of white and black inlay materials on the surface of the greyish Korean celadon clays. This technique dates from the mid-12th century in Korea, and it allowed sharp and finely detailed designs to be used beneath the bluish-green, transparent Koryŏ celadon glazes. In creating this style of ware the Koreans solved a problem that had eluded Chinese potters for centuries: that is, how to achieve well-contrasting and highly detailed designs with traditional high-lime glazes.

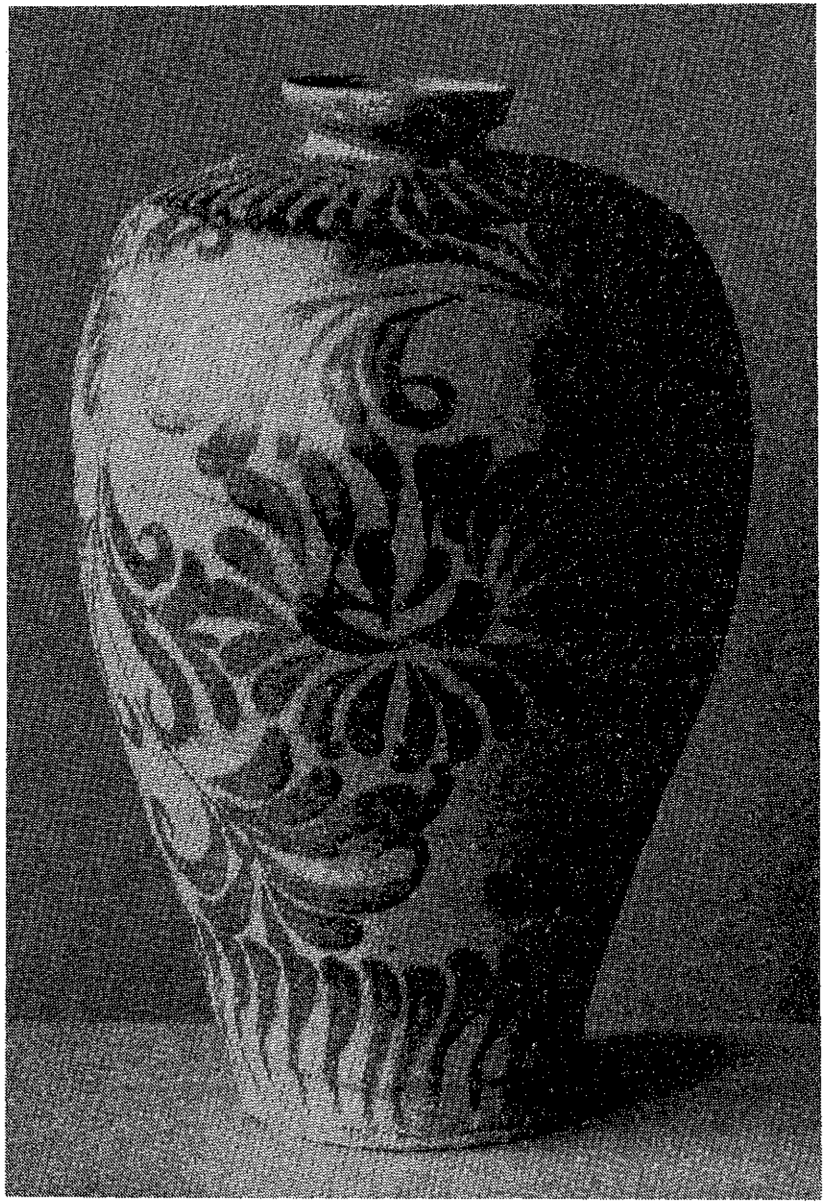

Figure 8 Maebyŏng *vase with painted iron-brown slip, covered with an amber glaze.* Korean, late 14th or early 15th c.; height 10.2"

Inlay is a relatively simple process. The designs are first carved, engraved, rouletted or stamped into the half-dry 'leatherhard' wares. Thick, coloured slips are then dabbed into the patterns with a brush until the designs are filled with slip, a process which may involve a series of applications to complete. After further drying, the surface is scraped or sponged level to remove surplus slip, leaving the impressed or carved designs in sharp detail and in contrasting colours. Unlike conventional slips, the materials used for slip-inlay should contain a good deal of non-plastic material so that they shrink less than the clay bodies beneath. This ensures that the inlaid designs are gripped firmly by the shrinking clays that surround them during the final stages of drying.

Such would be the usual approach for making slip-inlaid wares. However, there is some evidence that the inlay material was applied to some Korean celadon wares after a preliminary biscuit firing because some biscuit-fired Koryŏ sherds exist with 'empty' carved patterns.[2] In this case the inlay material would have needed to have had a very low shrinkage indeed, in both drying and firing, if it were not to contract visibly in the finishing processes.

Korean inlay under celadon glazes used two tones in particular: white and black (Figure 9). These have been investigated mineralogically (although not analysed quantitatively) by Vandiver. The white Koryŏ slip proved to be "quartz particles sintered with small amounts of glass and clay: x-ray diffraction indicates...minor amounts of mullite" (Vandiver *et al.* 1989: 370). Given this description and the proposed use of porcelain stone in Korean glazes, it seems possible that the material studied at the Smithsonian laboratories was a rather siliceous porcelain stone. However, full quantitative analysis would be necessary to test this proposal.

The black Koryŏ inlay slip has also been studied by electron microscopy and x-ray diffraction techniques at the Smithsonian. Vandiver found that anorthite had developed in the black inlay during firing— anorthite being a mineral that is only found rarely in the Koryŏ glaze itself. She suggests that the black inlay may have been a mixture of "black magnetite and ilmenite particles with the raw materials for the glaze," and she believes that it "was sintered to nucleate the crystals prior to inlaying [followed by] refiring to grow them" (Vandiver *et al.* 1989: 372).

Conclusions

Study of the technology of Koryŏ celadon is now well established, and the main features of this work that have emerged so far are as follows.

The kiln-complexes that produced Korean celadons exploited similar rocks and clays to those employed by the huge and ancient south Chinese stoneware and porcelain industries. Moreover, the stoneware-producing areas of southern Korea

2 Examples are held in the Fitzwilliam Museum, Cambridge, England.

Figure 9 *Celadon bottle with bluish-green glaze; inlaid in white and black with touches of copper-red within the four roundels.*
Korean, probably 13th c.; height 10"

and southern China appear to have been part of the same extensive geological system.

Both China and Korea began their stoneware-making with hand-built, paddle-beaten vessels that were rendered grey by reduction firing. In both regions, these unglazed stonewares developed from more ancient grey unglazed earthenwares that were made from near-stoneware materials. However, the time difference between the commencement of the Chinese and Korean stoneware traditions was probably at least 2000 years. On present knowledge, the first unglazed Chinese stonewares seem to date from about the 16th century BC and the first Korean stonewares from the 6th century AD. The first *glazed* Chinese stonewares may have been made as early as the 15th century BC, while the first Korean glazed stonewares are dated to the 10th century AD. In both China and Korea, a significant production of grey unglazed stoneware continued in parallel with the new glazed stoneware materials.

Chinese grey-green glazed stonewares from Jiangsu and Zhejiang provinces (now known as Yue wares) provided the models for the first Korean celadons, which were probably made in the late 10th century AD. Korean celadon wares that have been analysed show body compositions that are virtually identical to Chinese Yue wares.

Korean celadon potters also used smaller versions of the Chinese *long* kiln design to fire their glazed stonewares. *Long* kilns had been pioneered in south China in the Warring States period and were used in the country on a large scale from the 4th to 11th centuries AD to fire south Chinese Yue wares. The design appears to have been transmitted to Korea from China in the late Eastern Han Dynasty (AD 25-220). Initially, the Korean potters used their *long* kilns for grey earthenware production, but the design proved ideal for glazed stoneware.

The Chinese Yue ware glaze appears to have been made from mixtures of the Yue ware body material with wood ash in about 6:4 proportions. In reduction firing, this resulted in glazes with greyish-green colours. The chemical basis for this glaze was the 1170°C silica-alumina-calcia eutectic mixture.

The earliest Korean celadons seem to have been of the Yue 'clay and ash' type, but sometime in the 11th century, the characteristic Korean blue-green celadon evolved. It is proposed by the author that this glaze could have been made from mixtures of a white quartz-mica porcelain stone, combined with lesser amounts of wood-ash (Wood & Kerr 1992). The fine bluish tone, characteristic of Koryŏ celadon glazes, is due to ferrous oxide dissolved in a lime glaze; and the low titania contents of the Koryŏ celadon glazes seem to have prevented Koryŏ celadon colours from displaying the very pronounced green tones that are typical of most early Chinese celadon wares.

As for the beginnings of the Korean celadon tradition, excavation and analysis have shown that both kiln-types and clay bodies suitable for making stoneware were in use in Korea for hundreds of years before glazed celadon wares were made in the country. As kiln temperatures in Korea increased between the 6th to 10th centuries, unglazed stonewares began to be produced from similar materials to those already in use for Korean earthenware. Soon a glazing technology based on Chinese Yue ware

was developed in Korea, in the late 10th century, and this was adapted in the 11th century to exploit low-iron, low-titania Korean glaze raw materials. This characteristically Korean approach to stoneware glaze construction resulted in the extraordinary visual qualities for which Koryŏ celadons are now so universally admired.

Acknowledgments

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