Provenance Study of Famous Chinese Greenware Bodies Using Principal Component Analysis

C. T. Yap and Younan Hua

Department of Physics, National University of Singapore, Lower Kent Ridge Road, Singapore 0511

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This work is based on published analytical data of 69 pieces of Chinese greenware bodies from seven famous wares: Yue, Longquan, Southern Song Guan, Ru, Jun, Yaozhou, and Ge. It is possible to do provenance studies of these wares by the application of principal component analysis using major and minor chemical constituents (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, and TiO_2). The results show that not only are northern and southern greenwares completely distinct in the raw materials used, but in addition the southern greenwares are reasonably well segreated into groups belonging to Yue ware, Longquan ware (white body), Longquan ware (black body) and Southern Song Guan ware. Our analysis also confirms the production of Ge ware in the Longquan area.

Introduction

Scientific studies of Chinese porcelain through elemental or compositional analysis can be divided into two types: (a) Analysis of major and minor chemical constituents [1–10] and (b) Analysis of trace elements [11–22]. Such studies include the identification of antique Chinese porcelains according to the period or dynasty; the variation of silica, alumina, potassia, etc. as a function of time; the development of glaze types from lime glazes to lime-alkali glazes and finally to high-silica glazes.

In this paper we consider 69 pieces of greenware from seven famous sites: Yue ware, Longquan ware and Southern Song Guan ware in Zhejiang province; Ru ware and Jun ware in Henan province; Yaozhou ware in Shaanxi province; and Ge ware whose location of production is still incertain. Figure 1 gives their geographical location. We first discuss briefly famous greenwares, and then we do provenance studies of these wares by the application of principal component analysis using the published concentration data of the major and minor chemical constituents (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, and TiO_2) of these 69 pieces.

Reprint requests to Prof. Dr. C. T. Yap, Department of Physics, National University of Singapore, Lower Kent Ridge Road, Singapore 0511.

Famous Chinese Greenwares

Greenware is a generic term for a broad class of ceramic whose colour is given by iron oxide which is present in varying amounts from 1% to 5%; yellower or browner colours are given by ferric oxide while greener or bluer colours by ferrous oxide. Oxidising atmosphere would produce the iron oxide in its ferric state while reducing atmosphere would change the oxide to its ferrous state. The use of large dragon kilns excludes the possibility of controlling an even temperature throughout the kiln; thereby wares from the same firing can have a range of colours.

Table 1 gives the chemical composition of the 69 pieces of greenware bodies which are taken from the publications of Li Guozhen and Guo Yanyi [3], Guo Yanyi et al. [23] and Zhang Fukang [24]. These data were obtained by the conventional method of wet chemical analysis, which yields quite accurate results and has been described in detail in [3, 23, 25].

(a) *Yue Ware*

Yue ware, made in northern Zhejiang province in the general area around Hangzhou, has a long history from the second or third century to the tenth century. The earliest discovered Yue kiln centre is Deqing, which is about 25 miles north of Hangzhou. Production of greenware is presumed to date from Eastern Han (AD 25-220) and continued into the Six Dynasties (AD 220-589). Other kiln sites are south and south-east of Hangzhou and are listed in increasing

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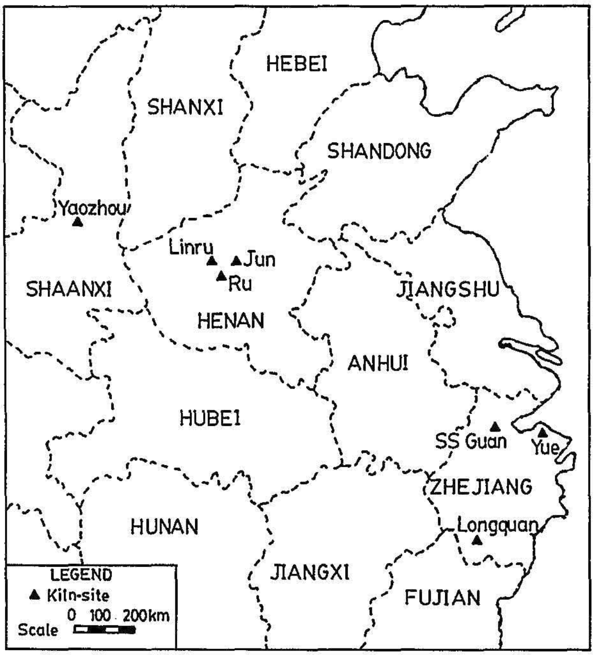

Fig. 1. Map of China showing the kiln-sites of Yaozhou, Linru, Jun, Ru, Southern Song Guan, Yue, and Longquan.

distance from Hangzhou as follows: Xiashan, Jiuyan, Shaoxing, Shangyu, Yuyao, Shanglinhu, and Ninpo. Two major kiln sites at Jiuyan and Shangyu, respectively 30 miles and 100 miles south-east of Hangzhou, were in operation from Eastern Han until the sixth century or soon after. At Shanyu, the dragon kilns established became the standard type for southern Chinese kilns up to the Ming dynasty (1368–1644). Kilns at Shanglinhu and Yuyao were in operation during the Tang dynasty (618–906) but the finest wares were made during the Five Dynasties (907–960). Evidence indicates that Shanglinhu produced the original mi se (secret colour) Yue ware which attained a new importance for its high quality, beauty and jade-like appearance. Soon after early Song (960–1280), the kilns producing Yue ware rapidly declined.

(b) Longquan Ware

The decline of Yue ware saw the rise of greenware production in hundreds of kilns in the Longquan region in south western Zhejiang province. Longquan kilns have been investigated since 1949. The principal ones were at Dayao, Zhukou, Xikou and Jincun, with Dayao situated about 25 miles southwest of Longquan producing the best quality and operating for the longest period. Extremely large volumes of greenware were produced by these kilns during Southern Song (1128–1279), Yuan (1260–1368) and Ming (1368–1644) dynasties both for home use and for export to as far as Istanbul, Cairo, and South Africa. In general, the later pieces are larger and heavier, with occasional elaborate decoration while the earlier pieces are smaller and simpler with little or no decoration. From Table 1, Longquan pieces have a higher content in alumina and potassia but a lower silica content than Yue pieces.

(c) Southern Song Guan Ware

Within a decade or two of Southern Song transferring the capital to Hangzhou in 1127, pottery kilns were set up near the Palace to produce Guan ware for the Song court. From ancient records, Southern Song Guan kilns were in two locations [26]. The one located at the foot-hill of Feng-huang in Hangzhou was known as internal kiln and the wares known as Xiu-Nei-Shi Kuan ware. However, the actual location for this kiln has not been discovered. The other kiln was located in Wu Gui Hill, northeast of a place known as Southern Song Altar (now known as Ba Gue Tian). Therefore it was known as Altar Guan kiln, which was built in 1132 [27]. This kiln site was discovered in 1956 by the Zhejiang Province Culture Relics Administrative Committee. Though undecorated, Guan ware had great appeal with its fine thin body and thick crackled glaze, like "the claw marks of crabs" left on the sand. Guan ware had a thick glaze of between two to five coats of glaze and the firing was done in a reducing atmosphere.

(d) Ru Ware

Ru wares were produced only for the imperial palace and have long been regarded as the acme of Song ceramics. They are "rare as stars at dawn". Presumably, they were produced for only about forty years and came to an abrupt end in 1127 when the Northern Song (96–1127) evacuated Kaifeng in Henan and moved to Hangzhou. Recently, the Ru kiln site was discovered at Baofeng Qingliangsi in central Henan. Ru ware is characterised by a yellowish body, thick unctuous glaze with no decoration. The base is covered with glaze and has three or five oval marks left by the spurs. Fish scale crackle is another characteristic of Ru products.

Table 1. Chemical Compositions (wt%) of Some Famous Greenware Bodies from Various Dynasties in Southern and Northern China.

No.	Ware Name	Code in Original	Dynasties and Type of Porcelain Bodies	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5
1	Yue Greenwater	SY8-5	Eastern Han (Shangyu)	75.40	17.73	1.75	0.31	0.57	3.00	0.49	0.86	0.03	
2		SY8-7	Eastern Han (Shangyu)	77.42	16.28	1.56	0.38	0.53	2.67	0.58	0.82	0.04	
3		SHT_1-(2)	The Three Kingdoms (Shangyu)	75.83	16.60	2.23	0.33	0.54	2.90	0.60	0.24	0.02	
4		SY-16	Western Jin (Shangyu)	76.60	16.09	1.88	0.30	0.57	3.00	0.89	0.85	0.02	
5		92	Tang (Xiangshan)	78.01	14.23	1.82	0.44	0.53	2.75	0.81	0.80	0.04	
6		143	Tang (Yuyao)	75.83	17.17	1.84	0.29	0.55	2.67	0.87	1.00		
7		145	The Five Dynasties (Yinxian)	76.94	15.79	1.74	0.34	0.57	2.65	1.00	1.05	0.03	0.10
8		147	The Five Dynasties (Linhai)	76.36	16.22	1.89	0.33	0.52	2.60	0.84	0.99	0.01	0.04
9		S6-1	Northern Song Yue	74.56	16.34	1.91	1.09	0.99	2.51	1.01	0.98	trace	
10		S6-2	Northern Song Bowl	75.23	16.48	1.92	1.03	0.76	2.93	0.96	0.84	0.02	
11	Longquan Greenware	NSL-1	Northern Song (White Body)	74.23	18.68	2.27	0.54	0.59	2.77	0.48	0.42	0.02	
12		SSL-1	Southern Song (White Body)	67.82	23.93	2.10	trace	0.26	5.32	0.32	0.22	0.03	
13		S3-1	Southern Song (White Body)	70.95	21.54	2.39	trace	0.06	4.54	0.43	trace	0.04	
14		S3-2	Southern Song (White Body)	69.76	22.39	1.80	trace	0.39	4.42	0.75	trace	0.05	
15		Y2-1	Yuan Dynasty (White Body)	70.77	20.13	1.63	0.17	0.74	5.50	0.82	0.16	0.07	
16		ML-1	Ming Dynasty (White Body)	70.18	20.47	1.71	0.16	0.29	6.02	0.97	0.19	0.10	
17		NSL-2	Northern Song (White Body)	76.47	17.51	1.28	0.60	0.34	3.08	0.27	0.42	0.02	
18		48	Southern Song (White Body)	68.90	23.46	1.35	0.51	0.29	4.61	0.49	0.18	0.07	
19		S-3-3	Southern Song (White Body)	73.93	18.36	2.43	0.31	0.67	3.16	0.22	0.39	0.15	
20		S-3-4	Southern Song (Black Body)	61.37	27.98	4.50	0.87	0.73	3.74	0.38	0.74	0.20	
21		LK_0-1	Southern Song (Black Body)	64.12	25.63	4.61	0.57	0.44	3.20	0.35	0.95	0.06	
22		LK_0-2	Southern Song (Black Body)	62.18	27.31	4.30	0.45	0.64	4.08	0.39	0.66	trace	
23		LK_0-3	Southern Song (Black Body)	63.79	25.54	4.07	0.76	0.51	4.34	0.36	0.63	trace	
24		LK_0-4	Southern Song (Black Body)	63.77	25.40	4.59	0.67	0.43	4.15	0.19	0.92	0.06	
25		LK_0-5	Southern Song (Black Body)	58.81	32.02	3.53	0.69	0.35	4.28	0.33	0.46	0.06	
26		LK_0-7	Southern Song (Black Body)	63.07	26.06	4.19	0.70	0.51	4.00	0.25	0.73	0.04	
27		LK_0-8	Southern Song (Black Body)	65.26	24.98	3.58	0.44	0.41	4.29	0.36	0.49	trace	
28		LK_0-9	Southern Song (Black Body)	64.73	24.77	4.25	0.69	0.50	4.19	0.26	0.55	0.04	
29	Southern Song Guan	SK-1	Southern Song	69.12	22.42	3.89	0.76	0.52	3.02	0.31			
30		SK-2	Southern Song	66.72	23.67	4.94	0.61	0.72	3.81	0.42			
31		S	Southern Song	68.99	22.21	3.57	0.82	0.60	3.51	0.33	0.09	0.03	
32		SK-3	Southern Song	68.72	22.37	3.62	0.79	0.58	3.46	0.38			
33		WJ_{10}	Southern Song	61.27	28.81	4.12	0.21	0.62	4.16	0.19	0.67		0.08
34		WJ_{13}	Southern Song	66.56	24.24	2.63	0.32	0.36	3.71	0.28	1.08		0.09
35		WJ_{15}	Southern Song	65.89	25.24	2.29	0.24	0.34	4.16	0.41	1.22		0.14
36	Ge Greenware	Y_1	Excavated from Dadu	63.04	27.03	3.55	0.11	0.69	3.33	0.54	1.33	0.01	0.17
37		Y_2	Excavated from Dadu	58.23	28.79	3.53	0.23	0.44	3.79	0.64	0.82		0.07
38		Y_3	Excavated from Dadu	58.72	28.95	3.36	0.19	0.39	3.74	0.60	0.73		0.14
39		SKO-1	Imperial Collection	63.33	25.97	3.31	0.42	0.56	2.68	0.74	1.27	trace	
40		LG_2	Ge Ware	62.68	28.69	3.74	0.53	0.54	4.15	0.14	0.08		
41		LG_3	Ge Ware	64.38	26.80	3.77	0.25	0.57	4.23	0.20	0.13		IL 0.21
42		Lg_5	Ge Ware	62.58	27.03	4.33	0.45	0.59	3.94	0.16	0.07		IL 0.59
43		LG_7	Ge Ware	64.19	25.24	4.50	0.20	0.65	3.96	0.13	0.80		
44		LG_9	Ge Ware	63.35	26.15	4.56	0.54	0.31	3.75	0.19	0.19		
45	Ru Green-ware	Ru-1	Ru Ware	65.30	27.71	2.20	0.56	0.42	1.86	0.17	1.24		0.10
46		S_1-1	Ru Ware	65.00	28.08	1.96	1.35	0.56	1.37	0.15	1.38	trace	
47	Linru Greenware	LR-1	Linru	64.11	29.44	1.97	0.54	0.41	1.64	0.29	1.14		0.10
48		LR-2	Linru	64.31	29.64	2.12	0.37	0.45	1.97	0.35	1.02	C 0.08	0.08
49		LR-3	Linru	63.15	30.17	1.90	0.28	0.42	2.00	0.37	1.19		0.09
50		LR-4	Linru	69.46	23.82	1.75	0.43	0.64	2.26	1.23	1.16	C 0.10	0.16
51		72	Linru	65.47	27.88	1.80	0.76	0.36	1.50	0.37	1.32		

Table 1. (Continued).

No.	Ware Name	Code in Original	Dynasties and Type of Porcelain Bodies	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5
52	Henan	61	Song, Yiyang Bowl Sherd	64.13	29.47	1.73	0.40	0.46	2.03	0.58	1.29		
53		62	Song, Naixiang Bowl Sherd	65.91	28.61	0.57	0.71	0.37	1.40	0.71	1.93		
54		69	Song, Baofeng Bowl Sherd	65.98	27.86	2.06	0.48	0.41	1.55	0.24	1.29		
55		118	Sui, Anyang Bowl Sherd	68.46	25.28	1.30	0.17	0.42	2.22	0.20	1.14	IL 1.05	
56		W_1	Excavated from Fenghsi Grave	67.29	26.94	1.11	0.59	0.53	1.86	0.20	1.17		
57	Yun Green-ware	S_2-1	Song Jun	64.40	27.37	2.51	0.76	0.68	2.74	0.32	1.22	trace	
58		Y_1-3	Guan Jun	65.19	25.00	3.19	0.74	0.70	2.55	0.33	1.16		
59		Chun-1	Song Jun	63.57	31.11	1.32	0.83	0.30	1.75	0.35	1.04		
60		RJ-1	Song Rujun	65.86	25.17	1.97	0.42	0.42	1.94	0.30	1.30	0.01	0.10
61	Yaozhou Greenware	S7-1	Song, Sherd	65.44	28.05	1.54	0.93	0.22	2.48	0.30	1.27	trace	
62		89	Tang, Bowl Sherd	66.49	26.22	2.20	0.43	0.77	1.60	0.12	1.55	0.01	
63		Z47	Song, Moulded Sherd	73.91	19.01	2.54	0.46	0.81	2.33	0.20	1.15	0.01	
64		Y_1	Song, Yaozhou Sherd	70.18	24.59	1.43	0.20	0.61	2.37	0.26	1.28		0.04
65		Y_2	Song, Yaozhou Sherd	72.60	21.92	1.55	0.21	0.62	2.42	0.24	1.18		0.06
66		Y_3	Song, Yaozhou Sherd	64.52	29.79	1.76	0.53	0.68	2.24	0.26	1.36	C 0.20	0.06
67		Y_4	Song, Yaozhou Sherd	72.16	20.28	1.71	0.38	0.78	2.59	0.35	1.16	C 0.07	0.14
68		SP-1	Song Sherd	71.50	22.43	1.34	0.93	0.22	2.48	0.30	1.17		
69		247	Song, Tongchuan Sherd	74.49	19.43	1.56	0.54	0.64	2.12	0.17	1.18	0.005	

(*e*) *Jun Ware*

Jun ware spread from Juntai which is in Xuxian in Henan province. In 1971, the Henan-Province Museum conducted extensive excavations at Juntai with the discovery of over a thousand ornate specimens. The main kiln centres for Jun ware from Northern Song were in Henan, southwest of Kaifeng, mainly around Yuxian and Linru, where the finest Jun wares were produced by late Northern Song. However Jun kilns were scattered widely. Jun wares are thickly glazed with ash glaze whose calcium oxide content is high. The bodies are also thick and strong, hence the widespread use in ordinary households during the Song and Jin dynasties. By early twelfth century, copper oxide was introduced to produce splashes of red or purple of indeterminate design, often seen in bubble bowls and jars. By the Yuan dynasty, the glaze has become duller with coarser grains.

(*f*) *Yaozhou Ware*

By late Tang, Yaozhou wares were produced in Huangbao near the town of Tongchuan in Shaanxi province and is about 70 miles north of Changan, the capital of the Tang dynasty. Although white, black and green wares were produced, greenware production dominated from the beginning of Song so much so that Yaozhou ware came to mean greenware. They are typically olive in colour and are characterised by thin deeply carved designs which first appeared in the tenth century. However, badly controlled reduction leads to duller colours of muddy brown. Moulding was introduced in the twelfth century, but owing to the deep cuts in the mounds, the finished product had the appearance of being carved. Yaozhou ware began to decline after the Song emperor moved south to Hangzhou.

(*g*) *Ge Ware*

During the Song dynasty, the five great wares of China have generally been taken as Ding, Ru, Jun, Guan, and Ge wares. Although Ge kilns have not been discovered, it seems that they should be in southern Zhejiang, presumably around Dayao. Ge ware could not be the same as Southern Song Guan ware made in Hangzhou, and this is clear from our studies. Ge means "elder brother". It can be divided into two types: Longquan Ge and "Handed-down" Ge. The difference is that the former has a thin body whereas the latter has a thick body. The ware was made with dark rim and iron foot, and the crackle was like "fish eggs" in thick glaze. There are indications that Ge ware was a Yuan dynasty product.

Principal Component Analysis

The objective of principal component analysis is to take multiple variables (in this case, the concentrations of the oxides of 8 major and minor constituents: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, and TiO_2) and find linear combinations with principal component 1 having the largest variance, principal component 2 the second largest variance and so on. Therefore if the data are highly correlated positively or negatively, we can reduce the number of dimensions drastically from 8 to 2 or 3 depending on the data, since in general there is a good deal of redundancy in the original variables, as most of them are measuring similar things.

For porcelain bodies, the concentrations of the oxides of 8 major and minor constituents measured on 69 samples from seven wares (Yue = 10, Longquan = 18, Ge = 9, Southern Song Guan = 7, Henan (Ru, Jun, etc.) = 16 and Yaozhou = 9), form a data matrix $X_{(N \times M)}$ where x_{nm} is the value of the concentration of compound m measured on sample n. The mean $\bar{x}_m$ and standard deviation s_m of the concentration of each compound are given by:

$$\bar{x}_m = \frac{1}{N} \sum_{n=1}^{N} x_{nm}, \qquad (1)$$

$$s_m^2 = \frac{1}{N-1} \sum_{n=1}^{N} (x_{nm} - \bar{x}_m)^2. \qquad (2)$$

To avoid the concentration of any compound from having too much influence on the principal components, the data were auto-scaled to have zero mean and unit variance:

$$z_{nm} = \frac{x_{nm} - \bar{x}_m}{s_m}. \qquad (3)$$

The principal components P are calculated [28] as linear combinations of the original variables (concentrations of compounds) such that the first principal component has the largest variance, the second principal component has the second largest variance and is orthogonal to the first, and so on. This is expressed as

$$P_{nk} = \sum_{m=1}^{M} z_{nm} v_{mk}, \qquad (4)$$

where P_{nk} is the value of the k^{th} principal component for sample n and v_{mk} the m^{th} term of the k^{th} eigenvector of the $(M \times M)$ correlation matrix.

Results and Discussion

Principal component analysis was performed on the 69 pieces of greenware bodies using the eight major and minor constituents: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, and TiO_2. The first principal component is

$$\begin{aligned} p_{n1} = &+ 0.57 z_{n1}(SiO_2) - 0.52 z_{n2}(Al_2O_3) \\ &- 0.42 z_{n3}(Fe_2O_3) - 0.06 z_{n4}(CaO) \\ &+ 0.16 z_{n5}(MgO) - 0.02 z_{n6}(K_2O) \\ &+ 0.38 z_{n7}(Na_2O) + 0.13 z_{n8}(TiO_2), \end{aligned} \qquad (5)$$

and the second principal component is

$$\begin{aligned} p_{n2} = &+ 0.13 z_{n1}(SiO_2) - 0.29 z_{n2}(Al_2O_3) \\ &+ 0.27 z_{n3}(Fe_2O_3) - 0.29 z_{n4}(CaO) \\ &- 0.02 z_{n5}(MgO) + 0.61 z_{n6}(K_2O) \\ &+ 0.17 z_{n7}(Na_2O) - 0.59 z_{n8}(TiO_2). \end{aligned} \qquad (6)$$

Figure 2 is a plot of principal components 1 and 2 for the 69 pieces of greenware bodies using the eight chemical constituents: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, and TiO_2. It is interesting to note that wares from northern China such as those from Shaanxi province (Yaozhou ware) and Henan province (Ru ware, Jun ware etc.) are located on the lower half of the plot whereas wares from southern China such as those from Zhejiang province (Yue ware, Longquan ware and Southern Song Guan were) are located on the upper half of the plot. This is presumably due to the largest coefficients (for K_2O and TiO_2) of (6) having a dominant effect on the second principal component p_{n2}. Since the value of the coefficient is positive for K_2O and negative for TiO_2, we can conclude that greenware bodies made in southern China have a higher percentage of K_2O and a lower percentage of TiO_2 than those made in northern China: this is also obvious from Table 1, indicating the use of rather different raw materials in Southern and Northern China. In general, Southern China is rich in porcelain stones, and porcelain bodies have a higher content of silica, while Northern China is rich in clay, and porcelain bodies contain more alumina.

(a) Wares of Northern China

Although southern and northern wares are well segregated, Fig. 2 shows that there is appreciable overlap for wares from Shaanxi province (Yaozhou ware) and Henan province (Ru ware, Jun ware, etc.), indicating

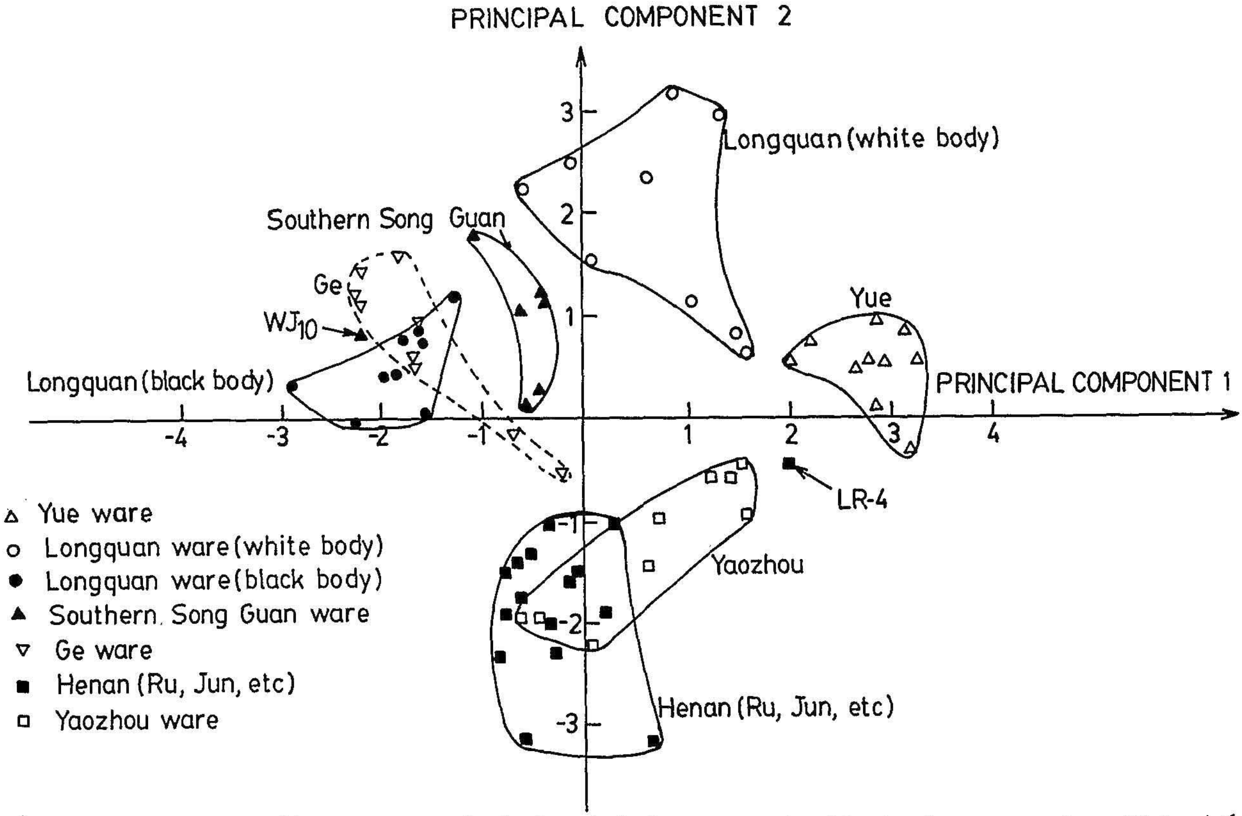

Fig. 2. Plot of 69 pieces of Chinese greenware bodies for principal component 1 and 2 using the concentrations of 8 chemical constituents (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, and TiO_2).

the use of rather similar materials in greenware production in northern China. However, Table 1 shows that Yaozhou wares in general have higher silica content and lower alumina content than those from Henan province. By (5), Yaozhou wares should be located more to the right of the plot, as is the case in Fig. 2, which shows that only three Yaozhou pieces overlap with those from Henan province. This indicates the use of similar but different raw materials which are mainly clays.

In Table 1, pieces indicated as Linru should be classified as Jun ware, and this also applies to those indicated as Henan, since recent archaelogical excavations indicate that places like Baofeng and Anyang also produced Jun ware. In Fig. 2, the Henan piece LR-4 falls far away from the group due to the extremely high Na_2O value of 1.23%. We feel that this is a mistake because the total becomes 101.01%. We think the value should be 0.23%, which would then give an acceptable total of 100.01%, and LR-4 would then be within the Henan group.

(b) Wares from Southern China

As noted above, wares from southern China are located on the upper half of the plot in Figure 2. Leaving the discussion of Ge ware below, Fig. 2 shows that Yue ware, Longquan ware (white body), Longquan ware (black body) and Southern Song Guan ware are all well segregated from one another. Yue wares have the highest silica content (75–78%) and the lowest alumina content (14–18%) and therefore are located at the extreme right of Fig. 2, in accordance with (5).

From Table 1, we see that Yue ware has higher silica content and lower alumina content as compared with the others. Composition variation is small from Eastern Han to Northern Song. Therefore, during these historical periods, porcelain stones were used as raw materials to make greenware bodies.

It is interesting to note that Longquan ware (white body) and Longquan ware (black body) are well segregated into two groups, with the latter falling on the left most region of Figure 2. This is due not only to the

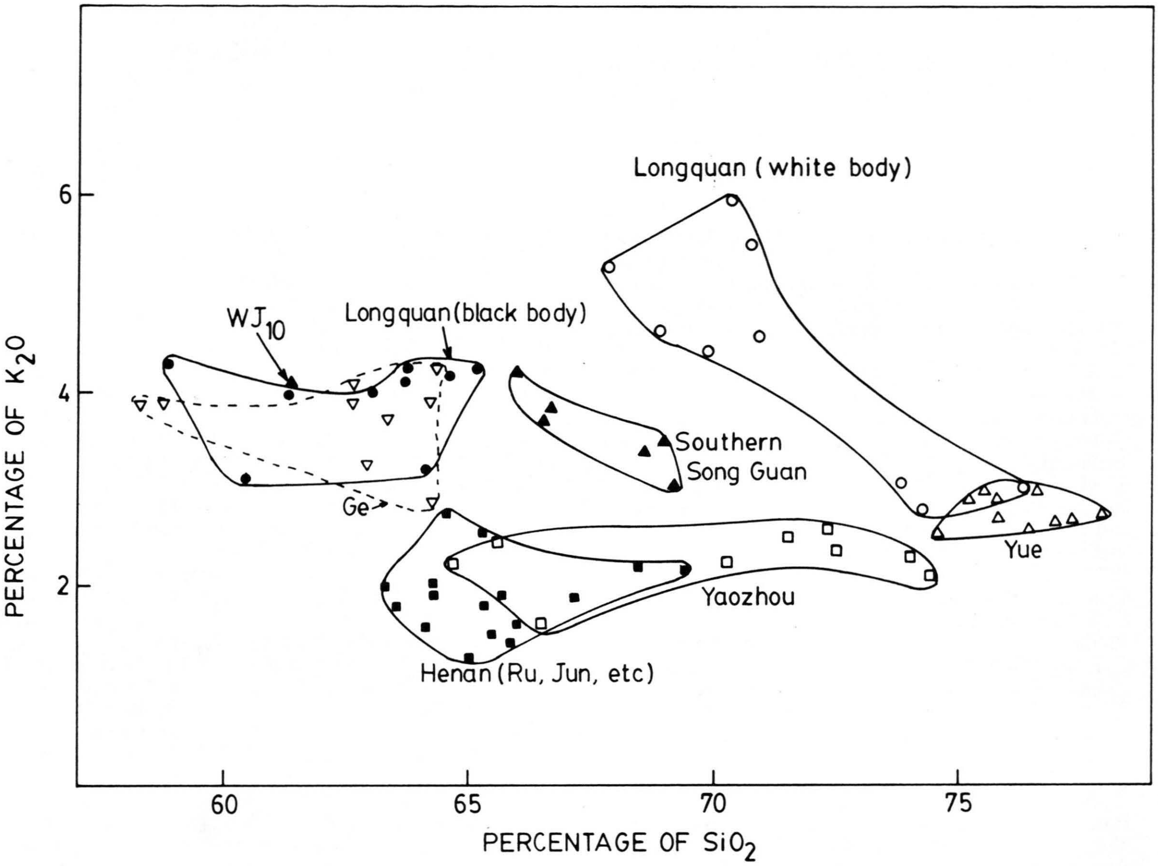

Fig. 3. Plot of the percentage of K_2O versus the percentage of SiO_2 for the 69 pieces of Chinese greenware bodies.

lower silica content and higher alumina content but also to the much higher iron content, so that the rather large negative coefficient (−0.42) of Fe_2O_3 in (5) pushes the location of the Longquan (black body) pieces to the far left of the plot. The difference between white and black body could be due to the addition of purple clay which has a higher iron and alumina content and a lower silica content than porcelain stone which is the main raw material used.

The location of Southern Song Guan ware in the upper half of the plot in Fig. 2 is as expected, since the production centre is Hangzhou in Zhejiang province of southern China. With the transfer of the capital of Northern Song from Kaifeng in the north to Hangshou, the technologies of Northern Song persist to some extent in Southern Song Guan ware. Therefore purple clays, which were also present in Zhejiang, were added to porcelain stones for the production of Southern Song Guan ware. One piece of Southern Song Guan (WJ_{10}) falls into the Ge group or the Longquan (block body) group, presumably due to a mistaken attribution owing to the similarity between Ge ware and Guan ware.

(c) *Ge Ware*

Although Ge kilns have not been found, present indications are that they should be in southern Zhejiang province, probably around Dayao, which is about 25 miles southwest of Longquan. This suggestion is strengthened by our analysis which shows appreciable overlap between Ge ware and Longquan ware (black body) with similar iron content. Figure 3 shows a plot of the percentage of K_2O against that of SiO_2 for all the 69 pieces under investigation. The almost complete overlap between Ge ware and Longquan ware (black body) again confirms the location of Ge kilns in the Longquan region.

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