第 35 卷第 8 期
2007 年 8 月

硅 酸 盐 学 报
JOURNAL OF THE CHINESE CERAMIC SOCIETY

Vol. 35, No. 8
August, 2007

汝官瓷和钧官瓷的主成分鉴别

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摘 要：为了解多种釉色汝官瓷和钧官瓷的原料来源、成分和分类关系，正确鉴别两窑瓷器，选取汝官瓷样品 34 个、钧官瓷样品 50 个，由质子激发 X 射线荧光分析测定了样品的化学组分。将所有样品的 7 种主成分数据进行统计分析，得到以下分析结果：汝官瓷胎的 Al_2O_3 平均含量明显高于钧官瓷胎的，而 CaO，TiO_2 的平均含量比钧官瓷胎的略高；汝官瓷胎的 SiO_2，Fe_2O_3，K_2O 平均含量明显低于钧官瓷胎的，而 MnO 平均含量比钧官瓷胎的稍低。汝官瓷釉的 Al_2O_3，CaO 平均含量明显高于钧官瓷釉的，而 K_2O，MnO 的平均含量比钧官瓷釉的略高；汝官瓷釉的 SiO_2 平均含量明显低于钧官瓷釉的，而 TiO_2，Fe_2O_3 平均含量比钧官瓷釉的稍低，即汝官瓷釉和钧官瓷釉的主成分平均值是不相同的。模糊聚类分析表明：多数汝官瓷胎、钧官瓷胎样品的原料产地和成分接近但有所不同，汝官瓷釉和钧官瓷釉的原料产地和配方则明显不同。从主量化学组成上可以较好的区分汝官瓷釉和钧官瓷釉样品。

关键词：汝官瓷；钧官瓷；主成分；模糊聚类分析；鉴别
中图分类号：TQ17，K87 **文献标识码：**A **文章编号：**0454–5648(2007)08–0998–09

DISCRIMINATION OF MAJOR COMPOSITIONS OF RU GUAN PORCELAIN AND JUN GUAN PORCELAIN

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Abstract: Thirty-four samples of Ru Guan porcelain and fifty samples of Jun Guan porcelain (both kinds being in different glaze colors) were selected to study the sources of raw materials, ingredients and their classification relationships. Proton-induced X-ray emission was applied to determine their chemical elements. The data of seven major chemical compositions collected from these samples were further analyzed. Results indicate that the average content of Al_2O_3 in the Ru Guan porcelain bodies is apparently greater than that contained in the Jun Guan porcelain bodies, and the average content of CaO and TiO_2 is slightly greater than that in Jun Guan porcelain bodies. The average content of SiO_2, K_2O and Fe_2O_3 in Ru Guan porcelain is clearly lower than that contained in Jun Guan porcelain bodies, while the average content of MnO is slightly lower than that contained in Jun Guan porcelain bodies. The average content of Al_2O_3 and CaO in Ru Guan porcelain glaze is apparently greater than that contained in the Jun Guan porcelain glaze, and the average content of K_2O and MnO is slightly greater than that contained in the Jun Guan porcelain glaze. The average content of SiO_2 in the Ru Guan porcelain glaze is clearly lower than that contained in Jun Guan porcelain glaze, while the average content of Fe_2O_3 and TiO_2 is slightly lower than that contained in Jun Guan porcelain glaze. Fuzzy cluster analysis indicates that the places of origin of the raw materials and elements of the majority of the Ru Guan and Jun Guan porcelain body samples have something in common, but some differences do still exist. The places of origin of the raw materials and components of the Ru Guan porcelain glazes differ significantly from those of the Jun Guan porcelain glazes. Therefore, the Ru Guan porcelain glaze samples and the Jun Guan porcelain glaze samples can be differentiated from their major elements.

Key words: Ru Guan porcelain; Jun Guan porcelain; major composition; fuzzy cluster analysis; discrimination

The Ru kiln is one of the five famous kilns in use during the Song Dynasty (960–1279). Juntai kiln is affirmed the Jun Guan kiln by archaeologist in 1974. They are outstanding representatives of kilns for the production

收稿日期：2007–01–28。 **修改稿收到日期：**2007–03–14。
基金项目：国家自然科学重点基金(50432010)；国家自然科学基金(50572097)；河南省自然科学基金(0611011500)；中国科学院核分析技术重点实验室(K–113)资助项目。
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Received date: 2007–01–28. **Approved date:** 2007–03–14.
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of famous ancient Chinese porcelains, and they hold an important position in the history of Chinese ceramics, as well as the history of the world, owing to their extremely high artistic level and rich scientific connotation. The Ru Guan kiln site is located in Qingliangsi, Baofeng County, Henan Province, China, where the porcelains were fired for the royalty in the late Northern Song Dynasty. The body of this kind of porcelain is light gray in color, similar to incense ash. The colors of the thin glazes range from sky green, sky blue, light green and pea green to pale blue. In the firing for the porcelain including the glazed body, the body was put on nail supports in the kiln, which left very tiny marks on the fired porcelain. Owing to their fine shape and consummate workmanship, Ru Guan porcelains were regarded as the best in the Song Dynasty, and they hold a significant position in the ceramic history of China. As the Ru Guan kilns merely existed for a short period of time, all the products were used by the royalty. It is extremely difficult nowadays to obtain Ru Guan porcelains produced during the Southern Song Dynasty.[1]

The Jun Guan kiln is located in Juntai, Yuzhou City, Henan Province, China. Since the glaze on Jun porcelains was formed by double-glazing, the thick glaze layer on Jun porcelain has colorized patterns that resemble traces left by earthworms. The various bright glaze colors include sky green, sky blue, pale blue, rosy purple, crab-apple red, and grape purple. The Jun porcelain glaze could be characterized by its phantasmagoric colors. That is to say, before firing, the green glaze is only one color, but it can turn into a variety of glaze colors after firing, *i.e.*, “one color into the kiln, thousands of colors out of the kiln”. Thus, Jun Guan porcelain has a very high reputation. As the saying goes, “Gold can be priced, but Jun porcelain is priceless.”[2]

The porcelains produced in the two famous kilns are very valuable for scientific research, utilization and collection. The geographical location of the two kilns is shown in Fig.1. As the two kilns are located close to each other, the two kinds of Ru and Jun porcelains look quite similar, and therefore, it is often difficult to distinguish one from the other. Although some valuable studies on Ru Guan and Jun Guan porcelains have been made by scholars and scientists[3–4], the following questions still must be solved in the fields of archeology, science and technology: Did the porcelains’ raw materials originate from Qingliangsi, for the Ru Guan kiln, and from Juntai, for the Jun Guan kiln? How do they classify these porcelains? Is it according to their recipe? What kind of classification relationship do they have? What is meant by the saying that there is “no distinction between Jun and Ru porcelains”? How can one make an accurate differentiation between Ru Guan porcelains and Jun Guan porcelains without causing any damage to them?

Fig.1　The geographical location of the two kilns

In our research, the major compositions of Ru Guan and Jun Guan porcelains in different glaze colors were determined by the proton induced X-ray emission (PIXE) method. The PIXE data were further analyzed by the fuzzy cluster method.[5–7] The relationship between the two kinds of porcelain and the distinction method were studied.

1　Experimental procedure

1.1　Sample selection

Fifty samples of Jun Guan porcelain were selected from unearthed porcelain fragments that were taken from Fragment pit number H2 T7 in Juntai. This pit is the biggest of all the pits in terms of the quantity of porcelain fragments and the abundance of glaze colors. Thirty-four Ru Guan porcelain body samples were selected from the Qingliangsi kiln. The various glaze colors of these samples include sky green, pale blue, sky blue, sea blue, rose purple, crab-apple red and grape purple. All of the Jun Guan porcelain samples, and some of the Ru Guan porcelain body samples, were provided by the Institute of Cultural Relics and Archaeology of Henan Province.

1.2　PIXE analysis experiment

The PIXE experiments were performed in the NEC9SDH–2 Pelletron tandem accelerator in the Institute of Modern Physics, Fudan University. The external beam PIXE technique was used to determine the chemical compositions of the samples. A proton beam with an initial energy of 3.O MeV entered the air, passing a 7.5 μm Kapton film, and traveled through a 10 mm air layer before reaching the porcelain samples. Due to an energy loss in the Kapton film and air, the actual energy of the protons reaching the samples was 2.8 MeV. An ORTEC Si (Li) detector, with a differentiating rate of 165 eV FWHM, was used to measure the X-rays excited by proton beams. The chemical ingredients (Z>11) were identified by the GUPIX–96 program in accordance with the X-ray energy spectrum at 5.9 MeV.

2 Dynamic fuzzy cluster analysis of major compositions of porcelain bodies from the two kilns

2.1 Major elements of porcelain bodies from the two kilns

The code number, name, body color, body texture and data of the major compositions gained by PIXE analysis of the selected Ru Guan porcelain body samples and Jun Guan porcelain body samples are listed in Table 1 and Table 2 respectively.

2.2 Arithmetic mean values of two kilns porcelain bodies

The mean value, the standard error and the differential value of the two mean values of the main chemical components contained in the Ru Guan and Jun Guan porcelain bodies can be calculated from Table 1 and Table 2, and the calculation results are listed in Table 3.

From Table 3 we can see that the average content of Al_2O_3 in the Ru Guan porcelain body is apparently greater than that in the Jun Guan porcelain body, and the average content of CaO and TiO_2 is slightly greater than that contained in Jun Guan porcelain bodies. The average

Table 1 Major compositions of Ru Guan porcelain body (RGPB) with ashy gray color and compact and hard texture *w*/%

Code No.	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3
R39b	27.91	64.98	1.68	1.06	1.08	0.02	1.77
R40b	27.56	65.74	1.77	0.52	1.15	0.02	1.73
R41b	26.21	66.06	2.18	0.73	1.08	0.02	2.24
R42b	28.03	65.25	1.73	0.38	1.28	0.02	1.81
R43b	30.16	62.26	1.52	1.47	1.05	0.04	2.00
R44b	26.86	65.77	1.90	0.42	1.13	0.02	2.39
R47b	30.11	61.84	2.17	1.35	1.13	0.01	1.88
R260b	30.56	62.21	1.77	0.86	1.13	0.01	1.94
R271b	26.77	66.26	1.82	0.44	1.27	0.00	1.94
R275b	26.66	66.31	1.86	0.60	1.23	0.01	1.84
R288b	27.38	64.91	2.07	1.01	1.09	0.02	2.03
R291b	27.63	65.39	1.77	0.42	1.33	0.02	1.95
R295b	31.16	61.72	1.51	1.07	1.07	0.01	1.96
R330b	31.75	60.94	1.77	0.84	1.10	0.00	2.10
R331b	30.17	63.25	1.58	0.42	1.16	0.02	1.91
R332b	30.70	62.47	1.63	0.51	1.22	0.02	1.97
R333b	31.78	61.54	1.55	0.56	1.08	0.00	1.99
R334b	30.53	62.34	1.70	0.87	1.08	0.02	1.95
R335b	27.59	65.30	1.83	0.63	1.20	0.01	1.94
R336b	30.91	62.13	1.54	0.75	1.13	0.01	2.03
R337b	28.79	64.42	1.75	0.44	1.22	0.02	1.87
R338b	28.97	63.96	1.84	0.45	1.12	0.02	2.15
R339b	30.10	62.74	1.44	1.08	1.19	0.02	1.93
R356b	26.90	65.83	1.88	0.47	1.11	0.01	2.30
R379b	27.54	65.38	1.85	0.65	1.12	0.02	1.94
R380b	28.99	64.52	1.67	0.44	1.13	0.01	1.75
R381b	30.99	62.44	1.45	0.50	1.15	0.01	1.96
R382b	26.98	64.83	1.91	1.80	1.18	0.03	1.78
R384b	27.17	65.94	1.78	0.68	1.09	0.01	1.83
R385b	29.79	62.68	1.48	1.23	1.16	0.02	2.14
R386b	29.86	62.48	1.77	1.29	1.16	0.01	1.94
R387b	30.75	61.97	1.74	0.76	1.20	0.02	2.06
R388b	31.36	62.11	1.51	0.52	1.11	0.01	1.90
R389b	31.17	62.29	1.55	0.45	1.10	0.01	1.94

Table 2 Major compositions of Jun Guan porcelain body (JGPB) w/%

Code No.	Body color	Texture	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3
J83b	Gray	Compact and hard	26.50	65.30	2.46	0.52	0.97	0.02	2.55
J84b	Gray	Compact and hard	27.50	64.30	2.55	0.54	0.92	0.00	2.51
J85b	Gray	Porous	26.60	65.20	2.29	0.65	0.92	0.02	2.67
J86b	Gray	Compact and hard	25.40	66.40	2.37	0.65	0.98	0.02	2.61
J87b	Grayish white	Loose	27.00	63.90	2.71	0.62	0.99	0.02	2.46
J88b	Grayish white	Compact and hard	26.20	65.40	2.51	0.66	0.90	0.02	2.88
J89b	Gray	Porous	25.90	66.20	2.24	0.66	0.97	0.02	2.61
J90b	Gray	Compact and hard	27.70	64.60	2.38	0.53	0.97	0.02	2.38
J91b	Grayish white	Compact and hard	27.10	64.80	2.43	0.50	0.88	0.02	2.64
J92b	Grayish yellow	Compact and hard	26.80	64.70	2.60	0.63	0.96	0.02	2.73
J93b	Grayish yellow	Porous	26.40	64.70	2.65	0.64	0.86	0.02	3.06
J94b	Grayish yellow	Compact and hard	25.90	65.00	2.61	0.61	0.99	0.05	3.07
J95b	Grayish yellow	Compact and hard	26.90	64.70	2.54	0.58	0.90	0.04	2.65
J96b	Grayish yellow	Porous	26.50	64.40	2.67	0.62	0.96	0.04	3.1
J97b	Grayish yellow	Compact and hard	26.00	65.40	2.58	0.59	0.88	0.02	2.99
J98b	Gray	Compact and hard	25.70	66.10	2.49	0.64	0.92	0.02	2.61
J99b	Gray	Compact and hard	25.60	66.30	2.19	0.52	1.02	0.02	2.82
J100b	Gray	Compact and hard	26.00	66.00	2.37	0.61	0.97	0.02	2.72
J101b	Gray	Compact and hard	27.20	64.80	2.63	0.61	0.93	0.02	2.83
J102b	Grayish white	Loose	26.80	65.10	2.45	0.54	0.97	0.02	2.73
J103b	Grayish yellow	Compact and hard	27.10	64.90	2.55	0.55	0.94	0.00	2.63
J104b	Gray	Compact and hard	26.00	66.20	2.32	0.59	0.94	0.02	2.63
J105b	Gray	Compact and hard	25.80	65.70	2.48	0.60	1.02	0.02	3.07
J106b	Dark gray	Compact and hard	26.20	66.20	2.38	0.55	1.00	0.02	2.39
J107b	Grayish white	Compact and hard	27.90	64.00	2.69	0.453	0.96	0.02	2.33
J108b	Gray	Loose	25.90	65.50	2.72	0.57	1.04	0.02	2.43
J109b	Gray	Porous	26.50	65.20	2.36	0.66	0.98	0.02	2.67
J110b	Gray	Porous	25.60	66.00	2.32	0.69	0.97	0.02	2.81
J111b	Grayish yellow	Compact and hard	27.80	64.10	2.48	0.58	0.97	0.02	2.53
J112b	Gray	Compact and hard	26.30	66.00	2.30	0.55	0.93	0.02	2.73
J113b	Grayish white	Compact and hard	27.20	65.10	2.53	0.48	0.95	0.02	2.21
J114b	Gray	Compact and hard	27.30	65.00	2.38	0.49	1.06	0.02	2.24
J115b	Gray	Compact and hard	25.60	66.60	2.51	0.54	1.05	0.02	2.40
J116b	Gray	Compact and hard	27.00	65.40	2.48	0.50	0.98	0.02	2.18
J117b	Gray	Compact and hard	26.20	65.90	2.57	0.51	0.90	0.02	2.25
J118b	Gray	Compact and hard	26.80	65.60	2.40	0.54	0.99	0.00	2.13
J119b	Gray	Compact and hard	25.80	66.00	2.22	0.59	0.95	0.02	2.52
J120b	Dark gray	Compact and hard	26.60	65.40	2.37	0.59	0.99	0.02	2.56
J121b	Grayish white	Porous	25.90	66.30	2.30	0.64	0.97	0.02	2.49
J122b	Gray	Compact and hard	27.00	65.20	2.49	0.47	0.97	0.00	2.26
J123b	Gray	Compact and hard	25.80	66.30	2.20	0.88	1.02	0.02	2.58
J124b	Gray	Compact and hard	25.80	65.50	2.66	0.61	0.93	0.04	2.85
J125b	Gray	Compact and hard	25.70	66.40	2.29	0.47	1.06	0.00	2.45
J126b	Gray	Compact and hard	24.90	66.70	2.52	0.69	0.93	0.02	2.58
J127b	Gray	Compact and hard	25.80	66.40	2.39	0.59	1.01	0.02	2.54
J128b	Gray	Compact and hard	27.60	64.60	2.37	0.56	0.96	0.02	2.39
J129b	Gray	Compact and hard	27.40	64.10	2.72	0.61	0.92	0.00	2.94
J130b	Gray	Compact and hard	26.90	65.70	2.42	0.54	0.99	0.02	2.33
J131b	Gray	Compact and hard	27.00	65.30	2.28	0.47	0.99	0.00	2.14
J132b	Gray	Compact and hard	24.90	66.40	3.19	0.81	0.88	0.02	2.40

Table 3 Mean value and standard error of the main chemical components contained in Ru Guan and Jun Guan porcelain bodies %

Item	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3
$\bar{R}\pm\sigma$	29.11±1.73	63.77±1.68	1.73±0.19	0.76±0.35	1.15±0.06	0.015±0.01	1.97±0.15
$\bar{J}\pm\sigma$	26.44±0.73	65.42±0.75	2.47±0.18	0.59±0.08	0.96±0.05	0.020±0.01	2.59±0.25
$\bar{R}-\bar{J}$	2.67	−1.65	−0.74	0.17	0.19	−0.005	−0.62

$\bar{R}$ ——Averagy mass content of the components in RGPB; $\bar{J}$ ——Averagy mass contents of the components in JGPB; σ ——Deviation.

content of SiO_2, K_2O and Fe_2O_3 in the Ru Guan porcelain clearly lower than that in the Jun Guan porcelain body, while the average content of MnO is slightly lower than that contained in the Jun Guan porcelain body. The color of the Ru Guan porcelain body is ashy gray, but the color of the Jun Guan porcelain body ranges from dark gray to gray, grayish white and grayish yellow. Their difference in color, we believe, is caused both by the difference in their respective firing conditions and temperatures and by the difference in their chemical compositions.

2.3 Dynamic fuzzy cluster analysis of porcelain bodies from the two kilns

Fuzzy cluster analysis (FCA)[8] is a method, based on the fuzzy mathematical theory, which is used to establish concepts, discover laws and build mathematical models by way of a fuzzy matrix. FCA was used to classify these samples into a number of categories. The source of raw materials for each sample was characterized by the chemical compositions of the samples. The data of the major compositions of each Ru Guan and Jun Guan porcelain body sample obtained by the PIXE was further analyzed and classified with FCA. The results are shown in Fig.2. From Fig.2, it can be seen that the classification of samples is related to the threshold value λ. In accordance with the theoretic value, the optimum threshold value is set as 0.890. Then, these samples can be classified into seven categories as follows:

Category 1: Most of the Jun Guan porcelain body samples belong to this category. It includes forty-eight Jun Guan porcelain body samples with different glaze colors. These samples can be merged into one category when λ= 0.897. The locations of origin of their raw materials are comparatively concentrated in certain areas.

Categories 2 and 3: A few of the Jun Guan porcelain body samples belong to these two categories. Each of the two categories has only one sample, that is, J125b and J132b. The correlation between the two categories of the Jun Guan porcelain body samples is weak, and so is the correlation within the majority of Jun Guan porcelain body samples. If λ= 0.868, the two samples above and the majority of Jun Guan porcelain body samples can be merged into one category.

Category 4: This category only has one Ru Guan porcelain body sample, *i.e.*, the Qingliangsi Ru Guan porcelain body R41b. Its correlation with the majority of Ru Guan porcelain body samples is quite weak, whereas its correlation to a small number of Jun Guan porcelain

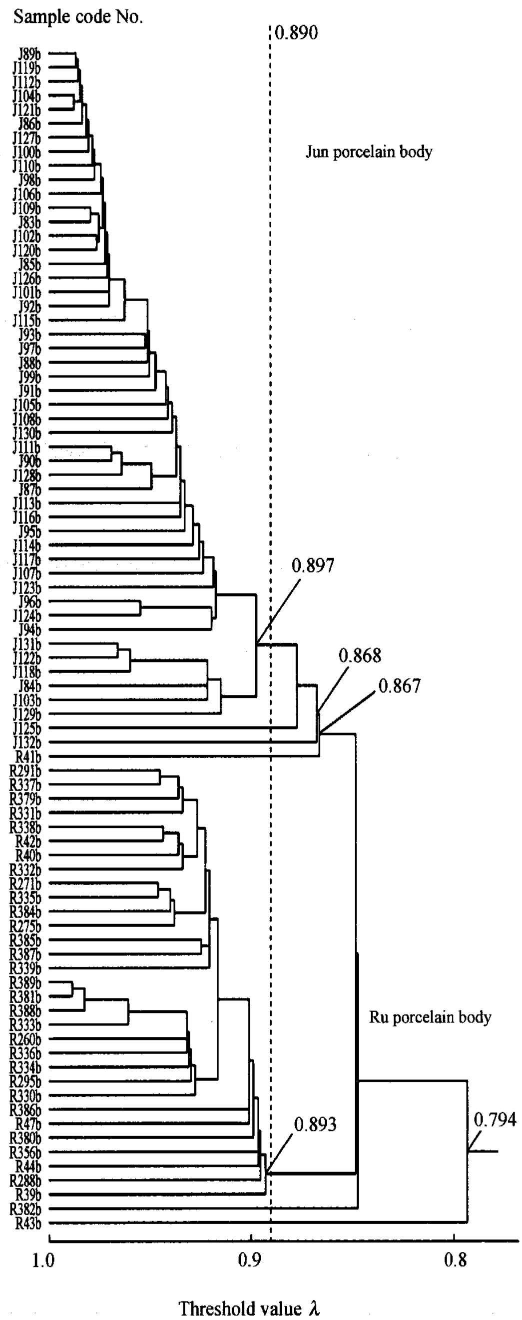

Fig.2 Trend FCA diagram of Ru Guan porcelain bodies samples and Jun Guan porcelain bodies samples

body samples is somewhat closer. This is probably due to the fact that the source of raw materials for this sample and that for a few Jun Guan porcelain body samples are closely related, but it may also be due to the fact that the sample had been disturbed by either man or nature.

Category 5: The majority of the Ru Guan porcelain body samples belong to this category. It includes thirty-one Qingliangsi Ru Guan porcelain body samples (ranging from R291b to R39b). When λ=0.893, these thirty-one Ru Guan porcelain body samples are clustered into one category. The locations of origin of the raw materials for these samples are comparatively close to each other.

Categories 6 and 7: A small number of the Ru Guan porcelain body samples belong to these two categories. Each category has one sample, namely R382b and R43b, respectively. Comparatively speaking, the relationship between the two Ru Guan porcelain body samples is weak, and so is their relationship with the majority of Ru Guan porcelain body samples.

Compared with the Jun Guan porcelain body samples, the locations of origin of the raw materials for the Ru Guan porcelain body samples are slightly scattered.

All of the above-mentioned Ru Guan porcelain body samples and Jun Guan porcelain body samples fall into one category when λ=0.794. This indicates that both the locations of origin of the raw materials for the porcelain body and the chemical compositions of the samples from the two kilns are close to each other. But Fig.2 shows that the majority of the Ru Guan and the Jun Guan porcelain body samples are obviously classified into two different categories. This means that the locations of origin of the raw body materials and the chemical compositions of the samples from the two kilns are different. One reasonable deduction is that the raw materials of the majority of Ru Guan and Jun Guan porcelain body samples might come from areas that are not far apart from other areas, and their chemical compositions are similar, although there are still some differences between them.

3 Results of dynamic FCA of the major chemical elements of the porcelain glazes taken from the two kilns

3.1 Major chemical compositions of porcelain glazes taken from the two kilns

The code number, name, location and the data of the major chemical compositions gained through PIXE of the selected Ru Guan and Jun Guan porcelain glaze samples are listed in Table 4 and Table 5. The glaze colors of five Jun Guan porcelain samples (*i.e.*, J83g to J87g) are red and blue. The glaze color of five Jun Guan porcelain samples (J88g to J92g) is sky blue. The glaze color of five Jun Guan porcelain samples (J93g to J97g) is sea blue. The glaze color of five Jun Guan porcelain samples (J98g to 102g) is rose purple. The glaze color of five Jun Guan porcelain samples (J103g to JI07g) is grape purple. The glaze color of five Jun Guan porcelain samples (J108g to J112g) is crab-apple red. The glaze color of ten Jun Guan porcelain samples (J113g to J122g) is pale blue. The glaze color of ten Jun Guan porcelain samples (J123g to JI32g) is sky green. The glaze colors of the Run Guan porcelain samples include sky green, pale blue, sky blue to pea green *etc*.

Table 4 Major compositions of Ru Guan porcelain glaze (RGPG) from Qingliangsi kiln *w*/%

Code No.	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3
R39g	16.13	61.73	4.52	14.03	0.15	0.08	1.87
R40g	14.90	64.51	4.44	12.28	0.17	0.11	2.10
R41g	16.08	63.94	5.59	10.78	0.18	0.10	1.82
R42g	14.97	64.74	4.77	11.82	0.16	0.16	1.88
R43g	15.46	62.78	5.14	13.03	0.18	0.14	1.77
R44g	15.54	64.44	5.80	10.71	0.19	0.10	1.73
R47g	15.83	64.79	5.23	10.44	0.17	0.18	1.87
R260g	15.34	65.75	5.07	10.42	0.14	0.11	1.67
R262g	13.20	64.34	4.54	14.12	0.19	0.21	1.91
R271g	14.76	65.45	4.47	11.47	0.15	0.12	2.08
R275g	15.17	63.41	4.81	12.85	0.16	0.15	1.95
R288g	15.21	63.47	5.11	12.51	0.17	0.13	1.91
R291g	14.88	65.40	4.91	11.42	0.18	0.12	1.59
R295g	15.36	66.03	4.71	10.51	0.16	0.11	1.61
R330g	15.75	62.64	4.28	13.59	0.18	0.16	1.90
R331g	14.89	64.49	4.78	12.43	0.22	0.14	1.54
R332g	13.04	67.81	4.05	11.62	0.20	0.19	1.60
R333g	14.68	64.00	3.43	13.97	0.21	0.19	2.03
R334g	16.72	63.78	4.79	10.97	0.17	0.14	1.93
R335g	15.56	64.03	4.12	12.63	0.19	0.12	1.86
R336g	15.02	64.47	4.91	12.31	0.16	0.13	1.52
R337g	15.39	62.29	4.55	13.95	0.22	0.17	1.94
R338g	14.70	65.71	4.45	11.74	0.18	0.15	1.57
R339g	14.94	61.57	4.01	15.80	0.14	0.17	1.87
R356g	16.18	64.16	4.67	11.51	0.14	0.12	1.71
R379g	13.19	66.89	4.18	12.21	0.19	0.16	1.68
R380g	14.81	63.08	4.37	14.13	0.18	0.19	1.73
R381g	14.39	66.09	4.99	11.18	0.14	0.14	1.56
R382g	15.05	62.12	4.34	14.82	0.22	0.20	1.76
R384g	15.93	61.82	4.60	14.03	0.14	0.11	1.88
R385g	15.55	66.98	4.60	9.36	0.14	0.12	1.75
R386g	15.51	67.00	4.64	9.22	0.15	0.12	1.86
R387g	14.85	64.39	4.83	12.51	0.16	0.16	1.60
R388g	14.58	63.26	4.41	13.64	0.23	0.17	2.23
R389g	14.70	65.93	3.92	12.05	0.19	0.15	1.57

3.2 Arithmetic mean values of porcelain glaze from the two kilns

The mean value, standard error and the differential value of the two mean values of the main chemical components contained in the Ru Guan and Jun Guan porcelain glazes can be calculated from Table 4 and Table 5, and the calculation results are listed in Table 6.

From Table 6 we can see that the average content of Al_2O_3 and CaO in the Ru Guan porcelain glaze is apparently greater than that contained in the Jun Guan porcelain glaze, and the average content of K_2O and MnO is slightly greater than that contained in the Jun Guan porcelain glaze. The average content of SiO_2 in the Ru Guan porcelain glaze is clearly lower than that in the Jun Guan porcelain glaze, while the average content of Fe_2O_3 and TiO_2 is slightly lower than that contained in the Jun Guan porcelain glaze. The results indicate that the areas of production of the raw material of the Ru Guan porcelain glaze and the Jun Guan porcelain glaze are obviously different.

Table 5 Major compositions Jun Guan porcelain glaze samples (JGPG) from Juntai Kiln *w*/%

Code No.	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Code No.	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3
J83g	9.71	72.30	4.47	9.58	0.21	0.05	1.94	J108g	9.35	73.80	3.07	9.00	0.20	0.06	2.06
J84g	9.06	74.10	4.13	8.41	0.21	0.06	1.76	J109g	9.69	72.90	3.45	9.00	0.21	0.06	2.86
J85g	9.59	69.90	3.37	11.90	0.22	0.06	2.19	J110g	9.86	71.90	3.08	9.95	0.22	0.06	3.01
J86g	9.23	74.00	3.87	9.16	0.27	0.08	2.02	J111g	9.56	74.90	4.38	6.97	0.21	0.05	1.69
J87g	9.48	72.60	4.39	9.42	0.23	0.03	2.22	J112g	9.17	73.80	3.17	8.69	0.22	0.03	2.51
J88g	9.69	73.60	4.33	7.85	0.23	0.04	2.50	J113g	9.68	71.40	3.98	11.5	0.25	0.02	2.15
J89g	9.56	73.30	3.8	9.47	0.20	0.03	2.24	J114g	9.66	68.50	3.77	13.4	0.20	0.05	2.74
J90g	9.68	73.10	4.35	8.23	0.23	0.06	2.49	J115g	9.64	71.80	3.83	10.90	0.24	0.05	2.63
J91g	9.62	73.70	4.01	9.04	0.20	0.05	2.05	J116g	9.45	71.90	4.16	10.20	0.21	0.07	2.71
J92g	9.37	73.90	4.33	8.24	0.25	0.06	2.41	J117g	9.64	72.10	4.29	9.99	0.25	0.02	2.86
J93g	9.92	73.10	3.98	8.54	0.20	0.04	2.54	J118g	10.70	70.60	4.30	9.77	0.28	0.07	2.43
J94g	9.39	76.80	4.21	6.41	0.22	0.02	1.50	J119g	10.50	72.70	3.86	9.15	0.27	0.05	2.07
J95g	8.97	76.40	4.49	6.90	0.23	0.03	1.89	J120g	10.60	72.00	3.99	9.00	0.26	0.06	2.78
J96g	9.45	75.10	4.35	7.60	0.17	0.03	2.17	J121g	11.70	70.80	3.82	9.22	0.24	0.05	2.13
J97g	9.59	75.40	4.72	6.76	0.20	0.05	1.79	J122g	10.10	71.20	3.99	10.6	0.24	0.09	2.52
J98g	8.85	74.80	3.66	9.11	0.20	0.03	2.08	J123g	9.55	72.10	3.94	10.4	0.20	0.04	3.09
J99g	10.3	73.00	3.82	9.01	0.24	0.09	1.86	J124g	9.50	72.70	3.91	9.31	0.23	0.03	2.82
J100g	9.94	71.40	3.34	11.10	0.15	0.06	1.85	J125g	9.90	73.50	4.19	8.83	0.19	0.03	1.93
J101g	9.27	73.50	4.33	9.27	0.21	0.06	1.82	J126g	9.74	72.50	3.52	10.1	0.28	0.10	2.72
J102g	9.65	73.80	3.71	8.95	0.16	0.03	1.72	J127g	9.09	73.10	3.69	9.83	0.24	0.03	2.88
J103g	8.83	75.20	4.38	7.54	0.23	0.04	1.34	J128g	9.96	72.70	5.06	8.58	0.23	0.03	2.13
J104g	9.53	71.80	3.11	10.20	0.24	0.03	2.80	J129g	9.33	72.40	4.20	9.89	0.24	0.03	3.04
J105g	9.63	71.70	3.31	10.80	0.22	0.09	2.45	J130g	9.52	73.00	3.90	9.50	0.24	0.04	2.37
J106g	9.43	73.10	3.51	9.43	0.22	0.06	2.82	J131g	9.49	69.70	3.77	12.7	0.26	0.07	2.89
J107g	9.31	74.60	3.89	8.24	0.21	0.05	2.13	J132g	9.56	72.50	3.59	9.24	0.28	0.07	2.85

Table 6 Mean value and standard error of the main chemical components contained in Ru Guan and Jun Guan porcelain glazes %

Items	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3
$\bar{R}\pm\sigma$	15.15±0.73	64.38±1.61	4.63±0.46	12.23±1.51	0.17±0.03	0.14±0.03	1.79±0.18
$\bar{J}\pm\sigma$	9.64±0.48	72.89±1.60	3.94±0.43	9.34±1.38	0.22±0.03	0.05±0.02	2.33±0.43
$\bar{R}-\bar{J}$	5.51	−8.51	0.69	2.89	−0.05	0.09	−0.54

3.3 Results of dynamic FCA of the major compositions of the porcelain glaze samples taken from the two kilns

By way of PIXE, we obtained the data of the major compositions of each Ru Guan and Jun Guan porcelain glaze sample. FCA was applied to the data, and the results are shown in Figure 3. In accordance with the theoretic value, the optimum threshold value λ was set to 0.850.

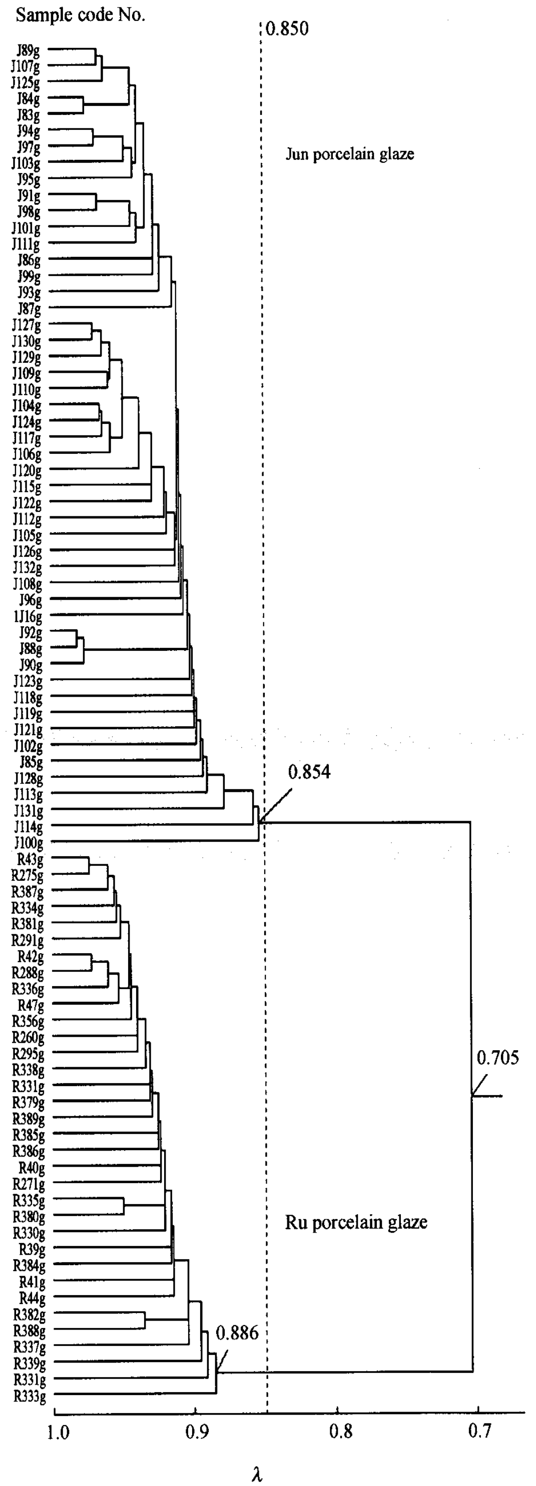

Fig.3 Trend FCA diagram of Ru Guan porcelain glaze samples and Jun Guan porcelain glaze samples

Accordingly, the samples can be classified into the following two categories:

The first category: Jun Guan porcelain glaze. In this category there were fifty samples with diverse glaze colors. They can be merged into one category when λ= 0.854. Comparatively speaking, the locations of origin of their raw materials and chemical compositions are close to each other.

The second category: Ru Guan porcelain glaze. This category included thirty-four samples with diverse glaze colors. They can be merged into one category when λ= 0.886. The locations of origin of their raw materials and chemical compositions are comparatively close to each other.

All of the above Ru Guan and Jun Guan porcelain glaze samples will fall into one category when λ= 0.705. This shows that the locations of origin of the glaze materials of the two kilns are not wide apart from one another. But Figure 3 shows that the Ru Guan and Jun Guan porcelain glaze samples are obviously classified into two different categories, which in turn indicates that the locations of origin of their glaze materials and recipes are distinctly different, so they are placed into two completely different categories. Why do people say that "there is no distinction between Ru and Jun porcelains"? This is probably because some kilns may have fired both Ru porcelains and Jun porcelains at different times, and these porcelains were similar or alike in their raw materials or firing processes. Since they looked so similar, it would be extremely difficult for to distinguish differences among them with the naked eye. As a matter of fact, distinctions do exist between the Ru Guan and Jun Guan porcelain body samples and glaze samples which were analyzed in our study.

4 Conclusions

(1) The average content of Al_2O_3 in Ru Guan porcelain bodies is apparently greater than that contained in Jun Guan porcelain bodies, and the average content of CaO and TiO_2 is slightly greater than that contained in Jun Guan porcelain bodies. The average content of SiO_2, K_2O and Fe_2O_3 in the Ru Guan porcelain is clearly lower than that in the Jun Guan porcelain body, while the average content of MnO is slightly lower than

(2) The average content of Al_2O_3 and CaO in the Ru Guan porcelain glaze is apparently greater than that in Jun Guan porcelain glaze, and the average content of $K_2O$and MnO is slightly greater than that contained in Jun Guan porcelain glaze. The average content of SiO_2 in Ru Guan porcelain glaze is clearly lower than that in Jun Guan porcelain glaze, while the average content of Fe_2O_3 and TiO_2 is slightly lower than that contained in the Jun Guan porcelain glaze.

(3) The locations of origin of the raw materials of the Jun Guan porcelain bodies samples are comparatively concentrated, and that of the Ru Guan porcelain bodies samples are somewhat scattered.

(4) The locations of origin of the raw materials and ingredients of the majority of the Ru Guan porcelain

bodies samples and Jun Guan porcelain bodies, samples are close yet different.

(5) The locations of origin of raw materials and components of the Ru Guan porcelain glaze samples and Jun Guan porcelain glaze samples are distinctly different.

(6) The Ru Guan porcelain glaze samples and Jun Guan porcelain glaze samples can be differentiated by their major elements.

Acknowledgments:

This program was supported by the National Natural Science Key Foundation of China (50432010), the National Natural Science Foundation of China (50572097), the Natural Science Foundation of Henan Province of China (0611011500), the Key Laboratory of Nuclear Analysis Techniques of the Chinese Academy of Sciences (K–113), and the Center for the Protection of Historical and Cultural Legacies of Zhengzhou University.

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汝官瓷和钧官瓷的主成分鉴别

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刊名：　硅酸盐学报 ISTIC EI PKU

英文刊名：　JOURNAL OF THE CHINESE CERAMIC SOCIETY

年，卷(期)：　2007,35(8)

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