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Integrating typological and stylistic characteristics with scientific results on the provenance study of of proto-porcelain from the Yejiashan Cemetery dating to the early western Zhou Dynasty

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Abstract

There has been widespread concern about the provenance of proto-porcelain in previous studies, which is fundamental in determining the origin of porcelain. However, there are still different opinions on the provenance of proto-porcelain. To discuss this question, this study analyzed 21 proto-porcelain shards, excavated from the Yejiashan Cemetery, on the basis of typology, petrography, and LA-ICP-AES methodologies. Three shards from the Panlongcheng site were also collected for comparative analysis. The typological analysis showed that the majority of proto-porcelain samples from the Yejiashan Cemetery were similar to those from Northern China in type, shape, decoration,and glaze color, while 2 shards showed typical Southern characteristics. The petrographic analysis indicated that there were two different patterns of distribution for quartz particles in the collected samples, which suggested the potential existence of at least two different origins. The LA-ICP-AES analysis results also supported two different origins for Yejiashan proto-porcelain and suggested that one may originate from Zhejiang Province in Southern China. In summary, our study has demonstrated the existence of at least two distinct provenance areas for the proto-porcelain sourced from the Yejiashan cemetery. This distinction is founded upon disparities in typological characteristics, distribution patterns of quartz particles, and chemical compositions. This conclusion contributes to a better understanding of cultural exchange between the *Zeng* state and neighboring regions and can shed light on the manufacturing industry of the early Western Zhou Dynasty (1046–771 BC).

Keywords Yejiashan Cemetery, Proto-porcelain, Provenance, Western Zhou Dynasty

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Introduction

As a great breakthrough in porcelain technology, proto-porcelain first emerged in the Erlitou period in Northern China and the Maqiao period in Southern China [1, 2]. Proto-porcelain was not only a symbol of technological achievement in ancient China, but also an important cultural relic which persisted throughout the Shang and Zhou dynasties with a wide distribution across different regions, capable, to some extent, of reflecting activities of ancient people and socioeconomic development. Therefore, research on proto-porcelain has always been a pivotal concern in both science history and archaeology [3, 4]. Most recent research indicates that so-called "proto-porcelain" is porcelain since it evidently aligns with the physicochemical characteristics of porcelain [3, 5]. Some scholars believe that proto-porcelain was made in several places like Jiangxi and Zhejiang in Southern China and traded massively to regions in Northern China [4, 6]. However, some studies assert a higher likelihood that proto-porcelain originated and developed independently in both Northern and Southern China based on significant differences in chemical compositions and microstructures between samples from Northern and Southern China [1, 8–11].

To investigate the origin of proto-porcelain, previous research has merely focused on proto-porcelain in the Shang Dynasty and/or earlier stages, while having some degree of unawareness of the Western Zhou Dynasty [1, 12–16]. Moreover, the provenance of proto-porcelain from adjacent areas of Nothern and Southern China has not yet been fully discussed. By combining methodologies of typology and scientific analysis, we can systematically and chronologically study proto-porcelain unearthed in a certain region, which will provide concrete evidence to support an understanding of the provenance and development of the porcelain industry in this region. The Yejiashan Cemetery is located in the middle reaches of the Yangtze River in Hubei Province, where a large quantity of proto-porcelain has been unearthed which provides valuable evidence for exploring the origins of porcelain during the Western Zhou Dynasty.

In this paper, 24 shards of proto-porcelain from the Yejiashan Cemetery and the Panlongcheng site were collected. Typology, thin-section petrography, and chemical elements were analyzed to determine the provenance of proto-porcelain from the Yejiashan Cemetery. The result will reflect, to a certain extent, the economy and technological standards of Hubei during the Western Zhou Dynasty, and reflect the monarchy control of the central plains area during the Zhou Dynasty.

Archaeological background of the Yejiashan cemetery

Hubei Province is located at the boundary between Northern and Southern China, where ancestors worked and lived continuously, leaving numerous significant sites and remains. In the Shang Dynasty, the Panlongcheng site was built to control mineral resources in the middle reaches of the Yangtze River [17]. The Panlongcheng site, built approximately 3500–3200 years ago, is located in the Huangpi District of Wuhan City in Hubei Province. After its discovery in 1954, the Panlongcheng site yielded large-scale structures such as city walls and palaces, as well as multiple high-level aristocratic tombs. Hundreds of artifacts, including bronze, pottery, jade, stone, and bone objects, were excavated. This site reflects the expansion of the Central Plains culture to the south during the Shang Dynasty (Sixteenth to thirteenth century BCE) and the development of a central urban center in the Yangtze River basin.

In the Spring and Autumn Period and the Warring States Period, the kingdoms of *Chu*, *Zeng*, *Yong,* and *Lu* were all established in Hubei Province [18]. The abundant relics excavated from *Zeng Marquis*(曾侯)Yi 's Tomb showed the extreme prosperity of the kingdom of *Zeng*. For a long time, academics lacked a clear understanding of the kingdom of *Zeng*'s early history due to a lack of historical documents and unearthed materials. The excavation of the Yejiashan Cemetery provides an opportunity to explore this important issue. Therefore, the Yejiashan Cemetery was voted among the "top ten archaeological discoveries of China in 2011". The Yejiashan Cemetery in Suizhou is a high-level aristocratic burial site, belonging to the Zeng State, dating back to the early Western Zhou period. This cemetery is located in the Jiangjia Village of Xiche Town in Suizhou City, more than 20 km away from the Zeng Marquis Yi's Tomb of Suizhou. The first phase of excavation of this cemetery was conducted by the Hubei Provincial Institute of Cultural Relics and Archaeology from January to June 2011. A total of 65 tombs and one chariot-and-horse pit were discovered. Excavations yielded 739 artifacts of various materials, including pottery, bronze, porcelain, jade, lacquered wood, and other artifacts. Experts revealed new information from different perspectives and published phased results, promoting in-depth research on *Zeng country* [19, 20]. Numerous precious cultural relics were excavated from the Yejiashan Cemetery, where there are more than 30 pieces of proto-porcelain of various shapes and types, including *Zun-vessel*, *Dou-vessel*, *Weng-vessel*, *Hu-vessel*, and *Guan-vessel*, [21]. The proto-porcelain shards attract extensive attention from archaeologists and historians. There is an existing debate on whether the shards were made locally or imported from other places, as well as their exact provenance [19, 22, 23].

Proto-porcelain samples

Twenty-one shards of proto-porcelain from the Yejiashan Cemetery and 3 shards of proto-porcelain from the Panlongcheng site were carefully selected for analysis and comparative studies.

Detailed information on the 24 pieces of proto-porcelain samples is presented in Table 1, where "YJS" represents the Yejiashan Cemetery and "HB" represents the Panlongcheng site in Hubei Province.

Figure 1 presents the geographical location information of all excavated proto-porcelain sites or tombs mentioned in the article.

Methods

Typology analysis

Archaeological typology is one of the basic tenets of archaeological research and is mainly used to study the morphological changes of relics and to find out their pattern of evolution. Typology combines stratigraphic judgment and contributes to determining the cultural nature of remains and to analyzing aspects such as, living conditions, social relations, and spiritual activities. It is widely used for the study of pottery, porcelain, and other artifacts that underwent significant change during the short periods over which they were used [24–26]. In our study, the proto-porcelain unearthed from the Yejiashan Cemetery was compared with those from Northern and Southern China during the same period before further scientific analysis.

Table 1 Detailed information of experimental proto-porcelain samples

Lab No	Original No	Type	Date
YJS1	M2:13	Bu-vessel	Early period of West Zhou
YJS2	M2:12	Zun-vessel	Early period of West Zhou
YJS3	M3:5	Guan-vessel	Early period of West Zhou
YJS4	M8:13	Pan-vessel	Early period of West Zhou
YJS5	M46:24	Zun-vessel	Early period of West Zhou
YJS6	M50:7	Dou-vessel	Early period of West Zhou
YJS7	M50:11	Zun-vessel	Early period of West Zhou
YJS8	M50:18	Weng-vessel	Early period of West Zhou
YJS9	M46:25	Bu-vessel	Early period of West Zhou
YJS10	M46:24	Guan-vessel	Early period of West Zhou
YJS11	M50:11	Zun-vessel	Early period of West Zhou
YJS12	M50:8	Guan-vessel	Early period of West Zhou
YJS13	M65 second-tier platform northern	Guan-vessel	Early period of West Zhou
YJS14	M65 western wall	Guan-vessel	Early period of West Zhou
YJS15	M27:76	Dou-vessel	Early period of West Zhou
YJS16	M27:77	Dou-vessel	Early period of West Zhou
YJS17	M27:82	Weng-vessel	Early period of West Zhou
YJS18	M27:97	Weng-vessel	Early period of West Zhou
YJS19	M27:98	Bu-vessel	Early period of West Zhou
YJS20	M27:99	Dou-vessel	Early period of West Zhou
YJS21	M27:115	Guan-vessel	Early period of West Zhou
HB4	M1:15 HB-4	–	Shang Dynasty
HB5	M1:85 HB-5	–	Shang Dynasty
HB6	M1:85 HB-6	–	Shang Dynasty

Thin-section petrography analysis

After being cut and polished, samples were made into euphotic thin-section with a thickness of 0.03 mm and viewed under a polarizing microscope (ECLIPSE LV100 POL, Nikon, Japan), with magnifications of × 50 and × 100. Due to restrictions based on the size of samples, 12 representative shards were analyzed.

Trace elements analysis by LA-ICP-AES

The chemical compositions of glazes and the bodies of samples were quantitatively analyzed by laser ablation-inductive coupled plasma-atomic emission spectrometry (LA-ICP-AES). A LEEMAN-Prodigy ICP-AES with a NEW-WAVE laser ablation system was used. The operating parameters were as follows: (1) RF generator: 40.82 MHz; (2) RF Power: 1.1 kw; (3) Argon flow rate: Plasma: 20 L/min; (4) Auxiliary pressure: 0 psig; Nebuliser pressure: 30 psig; (5) Laser: Nd-YAG; (6) Laser mode: Q-switched; (7) Laser Wavelength: 266 nm; (8) Output energy: 15.1 mJ; (9) Facular aperture: 610 mm; (10) Helium flow rate: 0.6 L/min.

Si was used as an internal standard, while Corning B, GSS, GSS2, GSS5, GSS6, and GSR1 standards were used as standard reference materials. Overall, 14 elements were determined, including Al, Fe, Mg, Ca, Na, K, Ti, Mn, Ba, Sr, Cu, Zn, Zr, and Sc. The SiO_2 data were calculated by subtracting the sum of all other elements in weight percent of oxides from 100%. According to the analytical results for the major and minor elements, most relative standard deviations are less than 1% for major elements, and less than 5% for trace elements.

Results and discussion

Results of the typology analysis

There are various types of proto-porcelain from the Yejiashan Cemetery, many of which were not yet observed in Hubei Province. Therefore, it is widely believed that these ceramics were imported from other places through trade or cultural exchange [19]. However, it remains unknown where these proto-porcelain were produced. Some experts infer they came from Zhejiang Province according to the S-shaped decoration and dark green glaze on some vessels, while others find that the body, glaze, decoration patterns, and shape of most proto-porcelain relics from the Yejiashan Cemetery are

Fig. 1 Location of sites/cemeteries involves in this paper. (1. Liulihe Cemetery in Beijing, Western Zhou dynasty; 2. Qianzhangda Cemetery in Shandong,Shang dynasty; 3. Beiyao Cemetery in Luoyang, Western Zhou dynasty; 4. Yingguo Cemetery, Western Zhou dynasty; 5. Changzikou Tomb, Western Zhou dynasty; 6. Guoguo Cemetery, Western Zhou dynasty; 7. Yejiashan Cemetery, Western Zhou dynasty; 8. Panlongcheng site, Shang dynasty; 9. kiln site in Deqing country, Western Zhou dynasty; 10. Ducangshan, Western Zhou dynasty; 11. Wucheng site, Shang dynasty.)

similar to those excavated from Northern China at that time, suggesting they came from Northern China [22]. The archaeological literature shows that, to date, 36 proto-porcelain objects have been excavated from the Yejiashan Cemetery, including *Dou*-vessel, *Bu*-vessel, *Lei*-vessel, *Zun*-vessel, *Weng*-vessel, *Gui*-vessel, and *Cap* (Table 2) [27].

After carefully comparing the types of proto-porcelain objects unearthed both in Northern and Southern China dating to the early Western Zhou Dynasty, it was found that the *Lei-vessel* and *Bu-vessel* types were common in Northern China, but hardly seen in Southern China [28–35]. It was also found that there were significant differences in the shapes of two kinds of *Zun-vessel* and *Gui-vessel* in Northern and Southern China. The *Zun-vessel* and *Gui-vessel* with a double ear design excavated from the Yejiashan Cemetery were similar to the *Zun-vessel* from the Yingguo Cemetry (M232:062) and *Gui-vessel* (M54:3) in Beiyao, Luoyang, respectively. Generally speaking, the proto-porcelain objects unearthed in the Yejiashan Cemetery have, more or less, the same type and shape as those from Northern China (Fig. 2).

Table 2 Number and type of proto-porcelain in Yejiashan cemetery

Type	Total number	Number of that with *cap*
Dou-vessel	15	2
Bu-vessel (jar with two handles)	6	5
Lei-vessel (jar with three handles)	5	1
Zun-vessel	4	–
Weng-vessel	4	–
Gui-vessel	1	–
Cap	1	–

It is worth noting that the phenomenon of intentional pre-burial damage to certain objects like the *Dou-vessel* in the Yejiashan Cemetery was similar to that of the

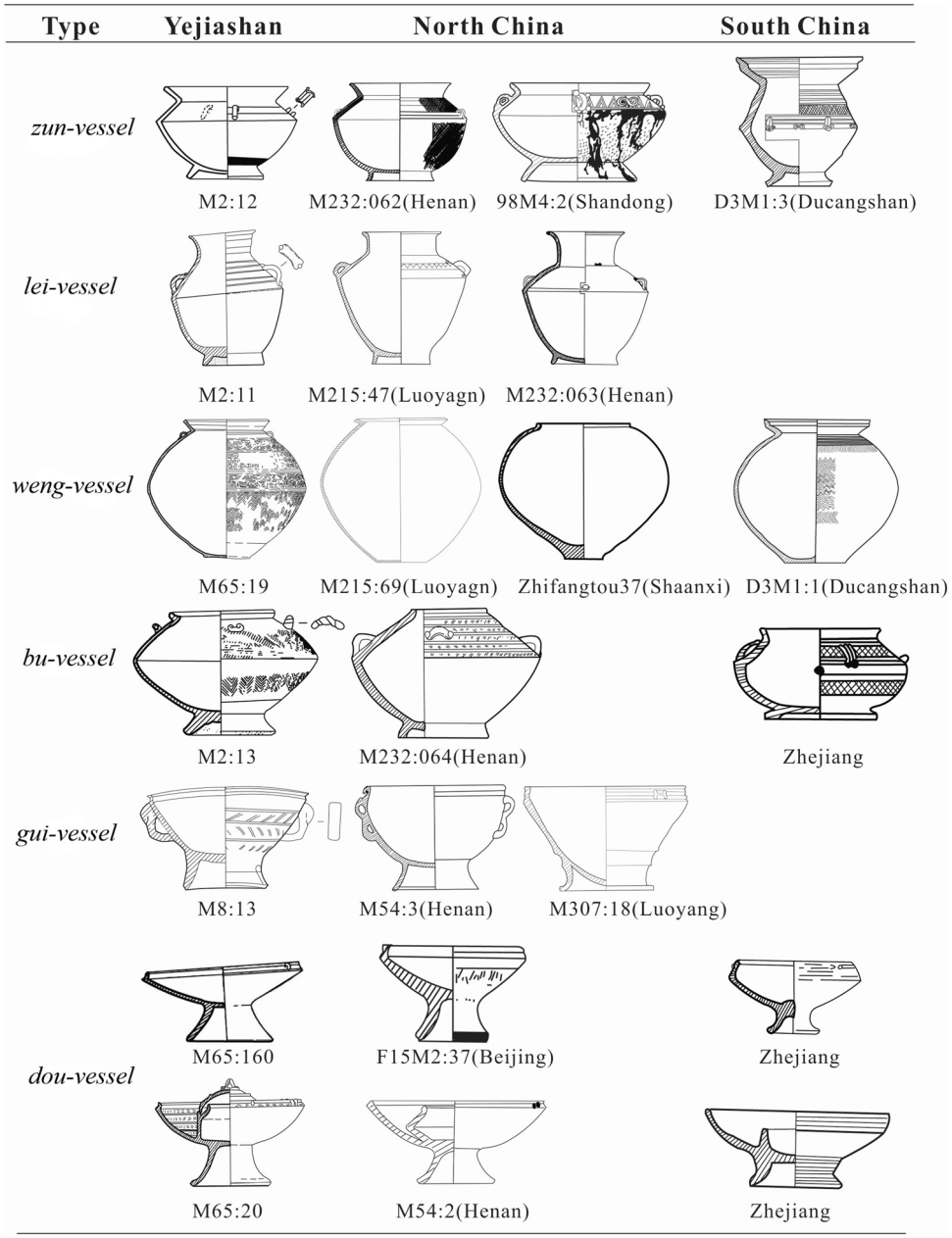

Fig. 2 Line drawing of proto-porcelains from Yejiashan Cemetery, Northern and Southern China in the same period

Changzikou tomb at Taiqing Palace, the Beiyao Cemetery in Luoyang and the Yingguo tomb in Pingdingshan, which are all located in Henan Province, Northern China [27, 28, 30]. The same specific burial custom in the four cemeteries indicated that the Yejiashan Cemetery was strongly influenced by Northern cultural factors.

The types and combinations of most vessels from Yejiashan, represented by the *Zun-vessel, Lei-vessel, Bu-vessel,* and *Gui-vessel,* were very similar to those unearthed in parts of Northern China, such as in Henan and Shaanxi. Meanwhile, some vessels found both in Northern and Southern China had similar shapes, such as the *Weng-vessel* and *Dou-vessel*. It is difficult to figure out where these vessels came from just by analyzing their type and shape. In this case, the glaze and decorative pattern must be discussed carefully together. As the excavation report shows, YJS17 and YJS18 are similar in shape, both having a trumpet-shaped mouth with an out-turned rim, convex grooves between the neck and shoulder, and a box pattern on the shoulder and body

[21]. Notably, the glazes of these two *Weng*-vessels were brownish green and dark green, which was more similar to those in the southern region, whereas products in Northern China often show light green and pea green. Another *Weng*-vessel from tomb 65(M65:19) had the same shape as YJS17 and YJS18, with a decorative pattern and glaze showing typical southern characteristics, including three cloudscape girdles on the shoulder, a chevron pattern on the body, and a brownish-green glaze [21]. This decorative pattern and glaze have been rarely discovered in Northern China, however, both were found on the *Weng-vessel* from Ducangshan and Quzhou in Zhejiang Province (Fig. 3). By all appearances, the *Weng* vessels are abundant in southern characteristics which supports the distinct possibility that they originate from Zhejiang Province.

Typological analysis showed that most of the proto-porcelain objects unearthed in the Yejiashan Cemetery were close to the northern counterparts in terms of combination, shape, ornamentation, and glaze, but there were still a few vessels with typical southern features. The following characteristics were combined with petrographic and trace element analyses and other scientific and technological methods to further explore provenance.

Results of the thin-section petrographic analysis

Thin-section petrographic analysis plays a crucial role in the study of pottery provenance, which reveals vast information like mineral composition, structural performance, and techniques in ceramic creation [36–40]. As is shown in Figs. 4 and 5, quartz particles from representative samples came in different sizes, with the majority ranging between 0 and 250 μm and some exceeding 500 μm. Quartz particles from most samples (except YJS17 and YJS18) were mostly white, faint yellow, or blue. Their body texture showed a floccus structure with a quantity of pores and air bubbles. On the contrary, the micrographs of YJS17 and YJS18 showed significantly different structures and grain distribution patterns. Quartz particles in these two samples were quite small, ranging from 0 to 25 μm, where the largest was not greater than 50 μm. The bodies were fine and vitrified matrices with few pores or bubbles. In addition, granular quartz in metamorphic clasts was found in the body of YJS1, indicating that the parent rock of the raw material of YJS1 may have been metamorphic [41].

To determine the size and distribution pattern of quartz grains in the bodies of samples, the scientific image processing software, Image Pro, was used to quantitatively analyze quartz particles in the body. Accumulative curves (Fig. 6) and probability cumulative curves (Fig. 7) were plotted as follows.

As is shown in Fig. 6, the abscissa axis indicates the particle diameter and the ordinate axis represents the accumulative area of particles. The accumulative area of particles refers to the sum of the areas of all particles in a specific range. Curves of YJS17 and YJS18 increased from 0 to 25 μm (diameter) and flattened after 25 μm, while curves of other samples showed a different trend where they increased in all the diameter ranges without peaking. Therefore, it was evident that there were at least two different distribution patterns of quartz particles in the samples from the Yejiashan Cemetery.

Compared with the accumulative curve, the probability cumulative curve more intuitively reflects the change in sizes of quartz particles. In the probability cumulative curve, the abscissa axis is the equivalent circle diameter of the particles, and the ordinate is the percentage of the total area of all the quartz particles in a specific range. If there are many grains of a certain size, there will be a corresponding peak in the curve. YJS8 and YJS17 were used as representatives of two different distribution patterns for comparison with their probability cumulative curves (Fig. 7). As shown in Fig. 7, YJS17 has an obvious peak

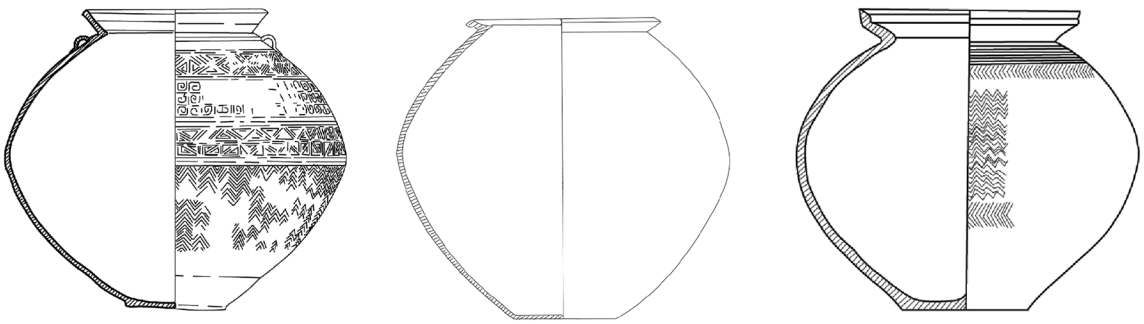

Fig. 3 the line drawing of *weng-vessels* from three sites

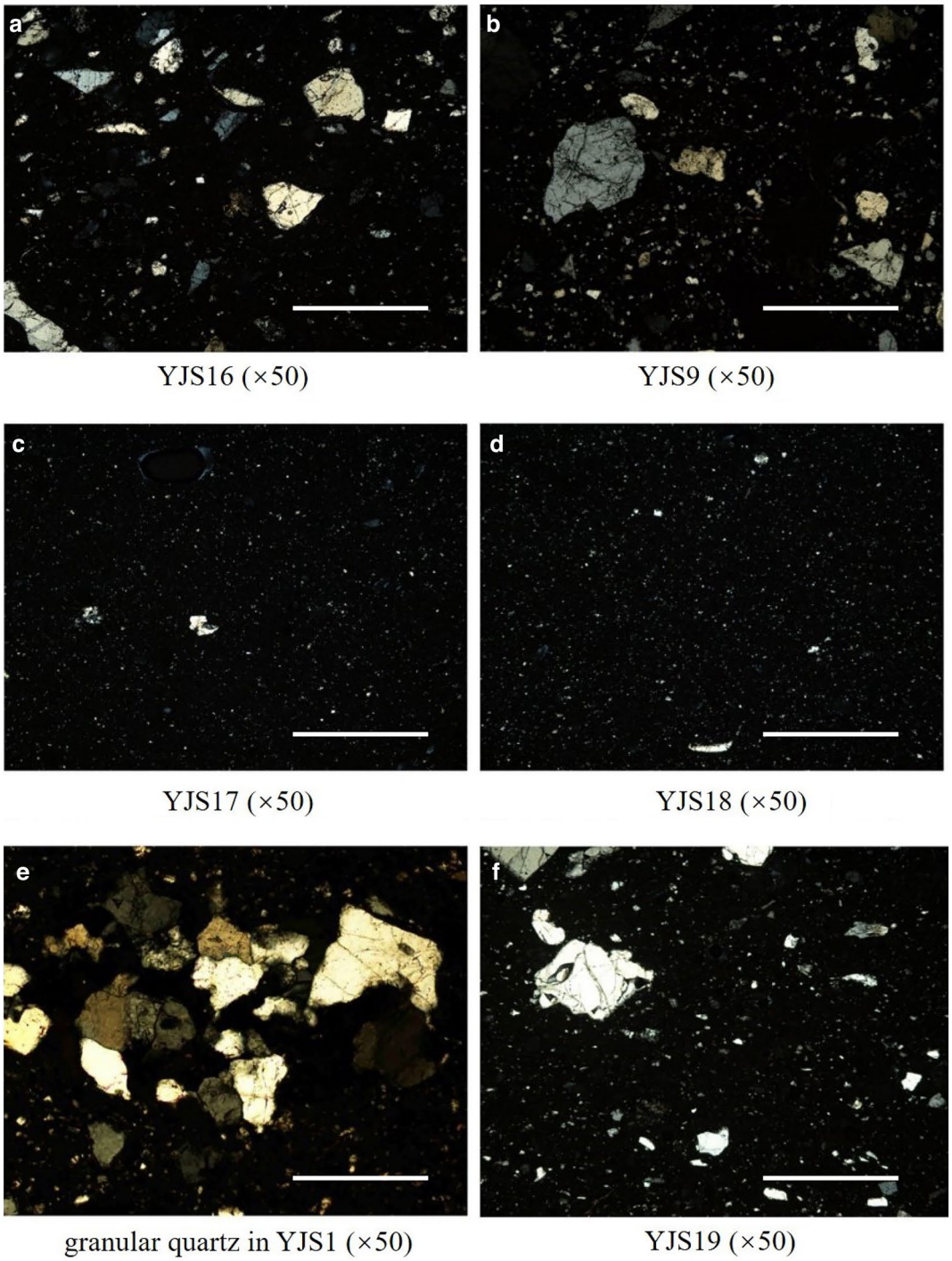

Fig. 4 the translucent microphotograph of samples from Yejiashan Cemetery (scale bar = 1000 μm)

at about 20 μm with the accumulative probability up to 55%, suggesting the sizes of most grains are about 20 μm; YJS8 shows several peaks from 0 to 250 μm, indicating the grain sizes of quartz particles were more dispersed.

The size and distribution of quartz particles in the bodies of the proto-porcelain samples were mainly affected by manufacturing processes of purification and selection, which were not directly related to the place of production. According to evidence of ancient ceramic

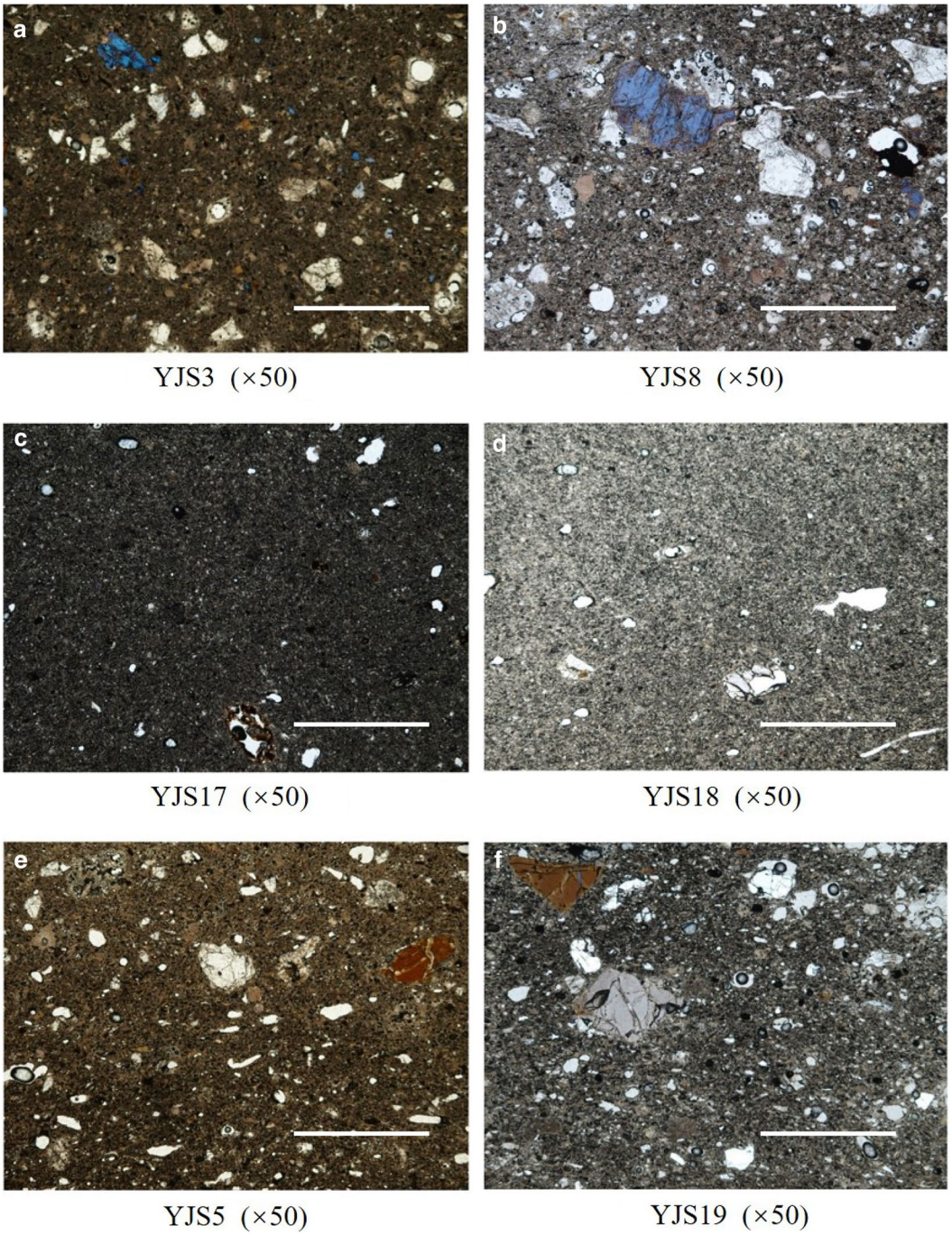

Fig. 5 the reflective microphotograph of samples from Yejiashan Cemetery (scale bar = 1000 μm)

production, vessels of the same type often share similar manufacturing techniques and production processes since they are uniform in size, shape, and function. YJS17 and YJS8 have the same *Weng-vessel* type, however, they differ in size and distribution pattern of quartz particles. Based on the theory of "similar type-similar manufacturing technology and productive processes", the difference in quartz particles between these two samples can probably be attributed to differences in raw materials. Therefore, the difference in petrography between YJS17 and YJS8 was very likely due to different clay materials, which means that the provenance of these two samples likely differs as well.

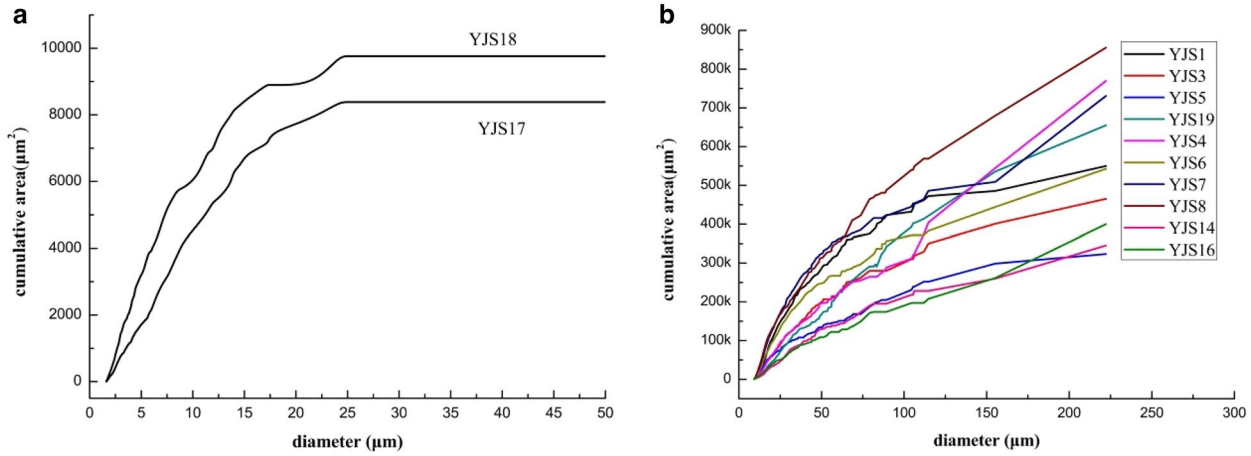

Fig. 6 Accumulative curve of quartz particles of analysed samples

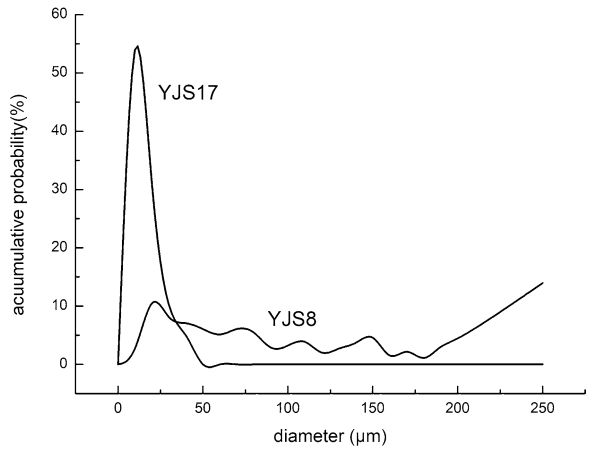

Fig. 7 Probability area accumulative curve of quartz particles of YJS8 and YJS17

Major and trace element composition analysis

It is believed that the trace element composition of ceramic objects carries characteristics of provenance since there are few differences between the composition and content of trace elements in porcelain of the same origin [42–44]. The Panlongcheng site and Wucheng site are two strongholds for the southern expansion of Shang culture during the Erligang stage. The Panlongcheng site belongs to orthodox Shang culture while the Wucheng site was originally a Shang colony but later turned into a localized polity [17].

Previous studies have shown that, in addition to the imported products from the Wucheng site, the Panlongcheng site may have also made proto-porcelain locally [45].

The Panlongcheng site is not far from the Yejiashan Cemetery, and both are located in Hubei Province. By collecting component data from a previous publication on proto-porcelain from the Wucheng and Panlongcheng sites [46] and comparing trace elements from proto-porcelain objects at the Yejiashan Cemetery, Panlongcheng site, and Wucheng site, Principal Component Analysis was conducted and box plots were drawn.

Based on the analysis of nine trace elements, namely Co, La, Sc, Eu, Fe, Mg, K, V, and Yb, Principal Component Analysis (PCA) was conducted. During the analysis, the Kaiser–Meyer–Olkin measure was determined to be 0.631, with all the elements exhibiting sampling adequacy exceeding 0.660, indicating the suitability of the dataset for PCA analysis. The first and second principal components represented 44.3 and 20.6% of the total information, respectively, accumulating close to two-thirds of the total information. Consequently, groupings based on the first and second principal components were deemed appropriate. Among these, the contributions to the first principal component were, in descending order, Mg, Eu, Sc, V, Co, and Fe, while the second principal component mainly consisted of Yb, La, and K. The analytical results are presented in Fig. 8. In the diagram, the clustering of the Yejiashan proto-porcelain was observed in the upper left quadrant, while the distribution of Panlongcheng and Wucheng fell within the lower right quadrant, clearly demarcating two distinct groups. It is unlikely that the proto-porcelain from the Yejiashan cemetery originated from the Wucheng region. This indicates that in the early Western Zhou period, after the Zhou dynasty conquered the Shang dynasty, there was likely a shift away from importing proto-porcelain from the Wucheng region, instead opting for new sources of proto-porcelain production. There were two data points located a little far away from the clustering of the Yejiashan proto-porcelain, which were samples YJS17 and YJS18.

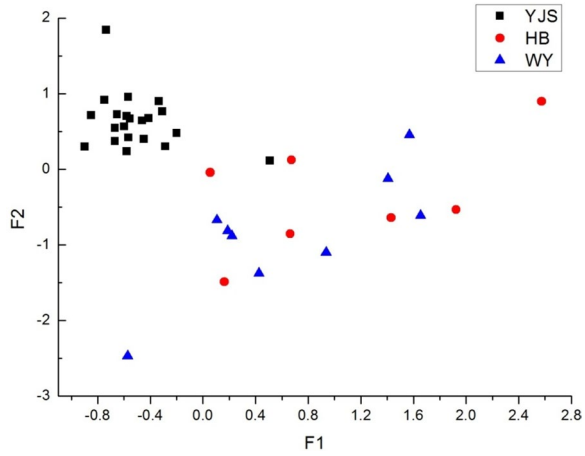

Fig. 8 The Factor load diagram of Factor 1 and Factor 2 in the body of proto-porcelains from Yejiashan Cemetery(YJS), Panlongcheng site(HB) and Wucheng site (WY)

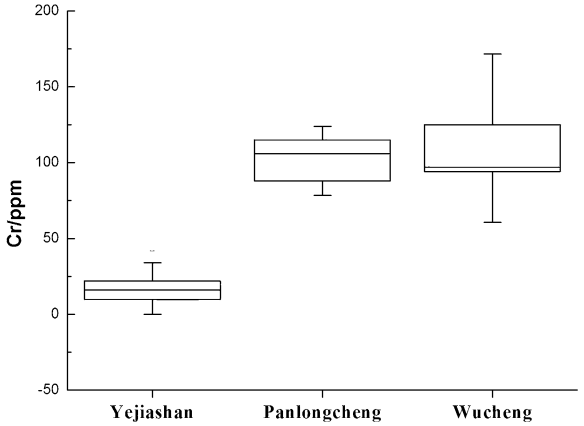

Fig. 9 Box plot of content of Cr in the body of proto-porcelains from three site

The box plot shows that the content of Cr in the Yejiashan Cemetery was much lower than that of the Panlongcheng site and Wucheng site (Fig. 9), suggesting different provenance. This confirmed the PCA results that proto-porcelain from the Yejiashan Cemetery was neither made locally nor from the Wucheng site.

According to the results of the thin-section petrographic analysis, samples from Yejiashan could be divided into two groups (YJSa and YJSb) based on the glaze color and accumulative curves. The YJSa

Table 3 The major chemical components of bodies of the proto-porcelains from Yejiashan Cemetery and Panlongcheng site (Wt %)

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2
YJS1	76.00	16.26	2.17	0.37	0.41	0.57	3.66	0.57
YJS2	80.73	13.92	1.65	0.46	0.16	0.17	1.96	0.95
YJS3	81.38	13.72	1.31	0.34	0.08	0.24	2.33	0.60
YJS4	78.80	14.96	1.56	0.48	0.59	0.35	2.46	0.80
YJS5	79.79	15.25	1.59	0.55	0.38	0.16	1.47	0.80
YJS6	77.36	16.48	1.77	0.48	0.17	0.33	2.49	0.91
YJS7	75.76	18.65	2.30	0.61	0.21	0.07	1.58	0.83
YJS8	77.37	15.46	1.98	0.29	0.25	0.56	3.56	0.54
YJS9	76.14	18.27	2.17	0.51	0.28	0.13	1.48	1.02
YJS11	78.43	16.52	1.81	0.55	0.10	0.08	1.71	0.80
YJS10	75.97	18.53	1.84	0.51	0.12	0.24	2.15	0.66
YJS12	72.96	18.26	2.03	0.42	0.35	0.77	4.63	0.58
YJS13	77.77	17.24	1.67	0.41	0.29	0.10	1.67	0.86
YJS14	73.23	17.69	2.17	0.37	0.65	0.58	4.77	0.54
YJS15	78.84	15.65	1.77	0.45	0.15	0.21	2.20	0.72
YJS16	77.93	15.39	1.98	0.41	0.14	0.17	3.39	0.60
YJS17	76.44	16.51	2.37	0.51	0.19	0.56	2.89	0.54
YJS18	74.32	19.37	1.79	0.55	0.17	0.55	2.56	0.69
YJS19	82.05	12.96	1.42	0.36	0.13	0.60	1.87	0.60
YJS20	77.42	16.63	1.82	0.41	0.14	0.24	2.63	0.72
YJS21	82.54	12.81	1.32	0.38	0.23	0.13	1.65	0.94
HB-4	73.40	20.07	1.66	0.73	0.23	0.25	2.77	0.88
HB-5	68.97	20.26	6.84	0.69	0.26	0.23	1.74	1.02
HB-6	73.18	19.90	1.70	0.73	0.79	0.15	2.71	0.84

Table 4 Trace chemical components of bodies of the proto-porcelains from Yejiashan Cemetery and Panlongcheng site (ug/g)

Sample	Mn	Ba	Cr	Cu	Ga	La	P	Sr	V	Zn	Zr	Y	Li
YJS1	252	678	10	18	20	31	198	83	42	837	364	11	12
YJS2	185	320	31	7	21	62	96	38	43	49	340	21	18
YJS3	270	332	7	3	19	65	0	33	0	16	349	35	16
YJS4	175	337	10	20	20	59	50	42	23	3520	235	24	19
YJS5	214	279	10	12	21	63	191	42	40	780	302	21	19
YJS6	199	371	16	2	20	64	73	45	25	18	392	25	18
YJS7	222	307	31	84	21	81	255	41	47	46	531	30	21
YJS8	268	680	16	27	19	33	43	94	20	7	360	14	11
YJS9	191	334	34	57	21	55	341	39	159	102	540	17	22
YJS10	222	290	19	4	20	84	56	35	0	55	263	37	15
YJS11	229	296	42	11	20	86	186	41	9	50	268	31	17
YJS12	259	786	22	15	20	34	26	106	38	33	271	15	14
YJS13	183	414	19	10	20	68	302	42	0	794	287	28	18
YJS14	249	807	20	12	20	33	74	103	21	148	308	17	12
YJS15	195	330	11	4	20	76	44	39	21	57	255	41	15
YJS16	219	380	9	3	20	110	4	47	0	11	272	40	20
YJS17	197	635	17	3	21	61	49	55	8	21	336	34	15
YJS18	188	595	34	7	20	79	95	56	48	73	233	25	20
YJS19	189	341	0	2	19	58	137	38	23	0	291	23	21
YJS20	195	373	12	3	20	77	64	34	14	30	391	26	18
YJS21	172	275	7	14	19	54	149	33	66	685	239	15	17
HB-4	146	403	101	11	20	47	99	50	82	52	286	31	38
HB-5	401	309	115	11	29	40	148	45	112	68	286	24	24
HB-6	154	394	88	26	20	46	167	49	98	61	218	30	40

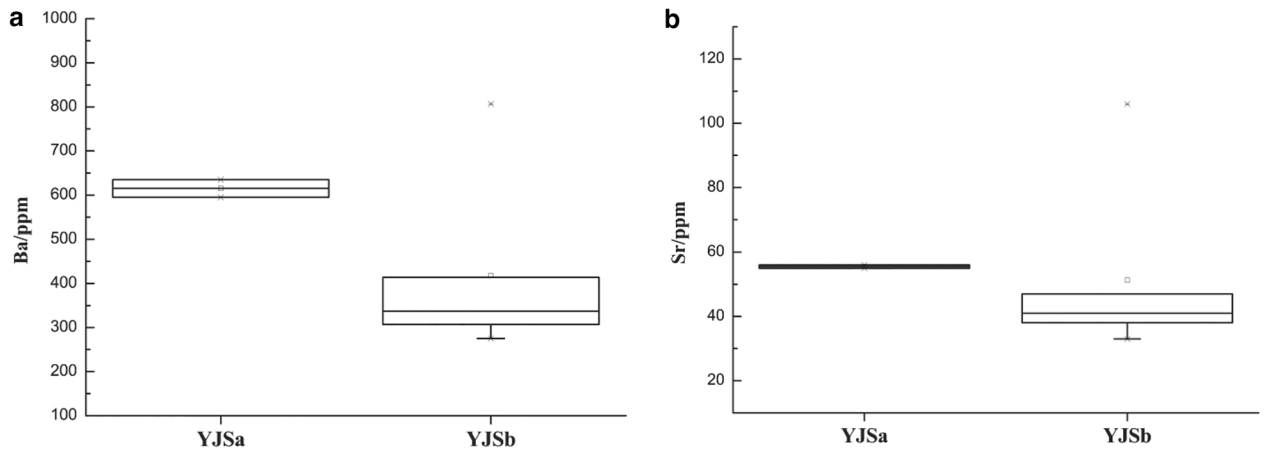

Fig. 10 Box plot of content of Ba, Sr in the bodies of samples from Yejiashan Cemetery

group includes YJS17 and YJS18, and YJSb includes all remaining samples. These two groups had significant differences in elemental composition (Tables 3 and 4), especially in the concentration of Ba and Sr (Fig. 10). It is not difficult to deduce that the samples of the two groups were made in different regions. Notably, Ba content in group YJSa was up to 635 ppm, which was higher than any other reported data on proto-porcelain bodies during the Shang and Zhou Dynasties [47]. Combined with evidence of typology and petrographic analysis,

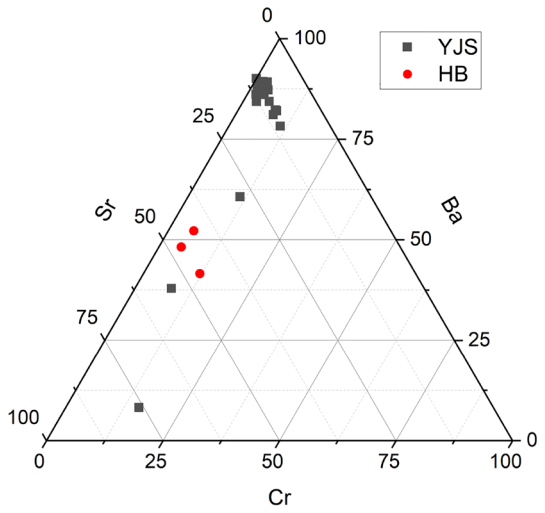

Fig. 11 ternary diagram of Cr, Ba, Sr in the bodies of samples from Yejiashan Cemetery(YJS) and Panlongcheng site(HB)

we believe that the YJSa group likely originated from Zhejiang Province, which is also partly supported by the latest technical analysis results [23]. The YJSb group likely originated from Northern China.

Regarding the analysis of the glaze layer on samples from Yejiashan, the compositional analysis revealed that its primary fluxing agent was calcium oxide, indicating a high-temperature calcium glaze (Table 5). This aspect indirectly corroborates its status as a proto-porcelain.

Finally, a ternary diagram of Cr-Ba-Sr was drawn (Fig. 11). In the diagram of Ba-Sr-Cr, samples from the Yejiashan and the Panlongcheng sites were plotted. The data points of samples from Yejiashan and Panlongcheng in the graph were widely separated, implying a limited relationship between the two locations. Within the Yejiashan samples, a few data points were notably distant from the rest, suggesting an alternative origin.

In summary, it can be seen from the above results there are at least two different sources contributing to the provenance of proto-porcelain unearthed in the Yejiashan Cemetery. Most samples likely came from Northern China, and a few (YJS17 and YJS18) came from Southern China. This phenomenon and result were extremely rare in previous studies and is likely related to the special geographical location of the north–south intersection of the Yejiashan Cemetery. It indicates that the early civilization of the Western Zhou Dynasty in the Han River basin, represented by the Yejiashan Cemetery, also

Table 5 the primary chemical components of glazes of the proto-porcelains from Yejiashan Cemetery and Panlongcheng site (Wt%)

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	BaO
YJS1	52.25	13.05	4.01	4.17	19.17	0.91	2.95	0.44	1.84	0.60	0.32
YJS3	66.72	15.47	1.78	1.71	8.32	0.40	3.23	0.52	0.77	0.63	0.23
YJS4	64.20	15.98	2.52	1.80	9.69	0.48	3.20	0.35	0.70	0.75	0.20
YJS5	64.76	17.18	2.27	1.63	6.84	0.42	5.09	0.30	0.56	0.66	0.18
YJS2	60.09	14.77	1.81	2.45	14.39	0.26	3.44	0.68	1.01	0.69	0.27
YJS6	59.88	14.98	2.12	2.69	13.49	0.52	2.84	0.88	1.08	0.81	0.34
YJS7	57.49	17.32	3.32	2.31	12.96	0.18	2.54	0.68	1.08	1.33	0.41
YJS8	54.92	13.23	4.05	3.04	18.90	0.70	2.70	0.21	1.07	0.64	0.24
YJS9	64.47	15.12	1.97	2.02	9.36	0.37	4.14	0.59	0.87	0.66	0.27
YJS10	54.14	17.22	2.34	2.35	16.72	0.57	3.23	0.68	1.36	0.74	0.37
YJS11	62.19	15.49	2.27	2.48	11.63	0.18	2.90	0.66	0.84	0.84	0.29
YJS12	55.27	12.86	3.64	2.95	19.21	0.71	2.76	0.22	1.14	0.60	0.25
YJS13	65.10	14.51	1.55	2.20	10.24	0.25	3.91	0.57	0.62	0.68	0.25
YJS14	61.53	18.07	3.79	1.91	8.30	0.59	3.98	0.21	0.48	0.66	0.27
YJS15	55.69	15.39	2.56	2.84	16.11	0.22	2.87	0.83	1.32	1.46	0.43
YJS16	56.77	12.86	1.85	3.09	18.96	0.28	2.34	0.91	1.69	0.64	0.38
YJS17	64.00	13.87	1.79	2.57	10.86	0.26	3.97	0.66	0.95	0.59	0.30
YJS18	59.50	17.02	3.73	3.20	10.17	0.86	3.19	0.34	0.80	0.62	0.32
YJS19	51.22	14.49	4.57	4.79	18.49	0.88	2.77	0.43	1.17	0.60	0.33
YJS20	62.20	16.77	2.09	2.07	10.63	0.42	3.33	0.48	0.90	0.69	0.23
YJS21	62.97	16.59	2.35	2.15	8.93	0.25	4.05	0.65	0.80	0.83	0.27
HB-4	58.34	17.44	1.84	2.54	13.50	0.15	3.61	0.18	0.68	0.80	0.20
HB-5	52.48	16.74	5.33	3.28	12.05	0.19	3.47	3.27	0.74	0.78	0.20
HB-6	57.70	18.00	1.82	2.37	13.96	0.19	3.40	0.17	1.75	0.69	0.27

absorbed the local cultural factors from the Yangtze River basin during the close interaction with the central plains culture.

Conclusion

Twenty-one pieces of proto-porcelain from the Yejiashan Cemetery (Additional file 1: Fig. S1) and 3 shards from the Panlongcheng site were analyzed in this study. Results of the typological analysis showed that the majority of samples shared a similar type, shape, decoration, and glaze color with proto-porcelain found in Northern China, while a few samples (YJS17 and YJS18) show typical southern characteristics.

In thin-section petrographic analysis, samples YJS17 and YJS18 had different quartz grain sizes and distribution patterns from other samples. The quartz particles in the bodies of YJS17 and YJS18 were smaller with clustering around about 25 μm, while other samples scattered from 0 to 250 μm. This phenomenon can be seen in the samples of the same type, indicating they were made by different clay materials from different places. In the chemical composition analysis, the bodies of samples YJS17 and YJS18 also had some richer trace elements such as Ba and Sr, suggesting their raw materials differed from other samples.

Our study identified at least two different provenance sources for the proto-porcelain from the Yejiashan Cemetery. Most samples probably came from Northern China, while there were still several vessels (YJS17 and YJS18) that were possibly imported from Zhejiang Province, Southern China. The pattern of provenance distribution indicated that the ancient kingdom of *Zeng* had economic and cultural exchanges with areas of the central plains.

As this study was confined by the number of samples, the complete picture of the provenance of proto-porcelains from the Yejiashan Cemetery is still not clear. However, evidently, by combining archaeological cultural analysis methods and scientific methods, studies on the provenance of proto-porcelain could be more systematic and multi-dimensional, with a more reasonable and reliable conclusion.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40494-023-01066-4.

Additional file 1: Figure S1. Ternarydiagram of SiO_2+Al_2O_3+[Na_2O+K_2O+CaO] in the body of Yejiashan samples and proto-porcelain from Shang Dynasty.

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Author contributions
LWG and WCS designed the research project; HFC provide the sample; LWJ and CY were responsible for the data collection and analysis; LWJ wrote the publication. All authors read and approved the final manuscript.

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Availability of data and materials
The data used in this research are published in this paper, and they are available from the corresponding author upon reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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References

1. Zhu L-T, Gao X-L, Zhang B, Bao Y, Zheng J-M. PIXE and FCA study on the provenance of proto-porcelain of Xia and Shang Dynasty unearthed from Erlitou and Yinxu sites, China. Nucl Instrum Methods Phys Res Sect. 2023;540:110–21.
2. Shanghai Management Committee Commission for Cultural Relics. 1993–1995 excavated report of the Maqiao site at Minhang. Shanghai Acta Archaeol Sini. 1997;2:197–236.
3. Yan L-T, Liu M, Sun H-Y, Li L, Feng X-Q. A comparative study of typical early celadon shards from Eastern Zhou and Eastern Han dynasty (China). J Archaeol Sci Rep. 2020;33: 102530.
4. Li W-J, Chen Y, Pollard MA, Wang C-S. The definition and origin of celadon—A re-discussion on the name of proto-celadon. J Archaeol Sci Rep. 2022;46: 103687.
5. Li Z-Q, Xiong Y-F, Zheng J-M, Wang X-Q, Zhou J-Z, Chen J, et al. Provenancing eastern Zhou proto-porcelain wares in the circum-Tai region. J Archaeol Sci Rep. 2020;29: 102179.
6. Huang S, Freestone I-C, Zhu Y-S, Shen L-H. The introduction of celadon production in North China: Technological characteristics and diversity of the earliest wares. J Archaeol Sci. 2020;114: 105057.
7. Li Z, Zhang L. Compositional characteristics of proto-porcelain production sites in the Dongtiaoxi river valley in Southeastern China. Archaeometry. 2021;63:577–93.
8. Li J-Z, Luo H-J, Gao L-M. Further study of the process of technological evolution of ancient Chinese pottery and porcelain. MRS Online Proc Libra. 1992;267:571–89.
9. Hao W-T, Zheng T-X, Li Y-D, Zheng J-M, Jian Zhu, et al. Provenance study of Chinese proto-celadon in Western Han Dynasty. Ceram Int. 2013;39:6325–32.
10. Zhu J, Solbrekken G, Hao W-T, Li Y-D, Zhen J-M, Zhen T-X, et al. Neutron activation analysis of bulk samples from Chinese ancient porcelain to provenance research. J Radioanal Nucl Chem. 2013;298:237–42.

11. Wu J, Wu J-M, Li Q-J, Li J-Z, Luo H-J, Deng Z-Q. Scientific studies on pottery and pro-porcelain from group of graves in Henglingshan Guangdong Province. Sci China Technol Sci. 2009;52:3085–91.
12. Yin M, Rehren T, Zheng J-M. The earliest high-fired glazed ceramics in China: the composition of the proto-porcelain from Zhejiang during the Shang and Zhou periods (c. 1700–221 BC). J Archaeol Sci. 2011;38:2352–65.
13. Yu G, Jin Z-Y, Chen L-F, Wang F, Wang X-R, Wu X-T, et al. Analyzing the earliest Chinese proto-porcelain: study on the materials from Liaotianjianshan kiln sites, Dehua County, Fujian Province (China). Ceram Int. 2018;44:21648–55.
14. Yan L-T, Huang Y, Liu L, Li L, Feng S-L, Feng X-Q, et al. A comparative study of the early high-fired ceramic shards from Dongtiaoxi, Zhejiang (China). Archaeometry. 2018;60:76–87.
15. Rehren Th, Yin M. Melt formation in lime-rich proto-porcelain glazes. J Archaeol Sci. 2012;39:2969–83.
16. Li Y, Zhang B, Cheng H-S, Zheng J-M. The earliest Chinese proto-porcelain excavated from kiln sites: an elemental analysis. PLoS ONE. 2015. https://doi.org/10.1371/journal.pone.0139970.
17. Li H-C. The center and periphery of the Early and Middle Shang Dynasty based on the production and circulation of bronze, stamped hard pottery, and proto-porcelain. Annu Rev Cult Herit Stud. 2018;51:108–23.
18. Lan Z, Gong Y-H. the Kinds and development of ancient kingdoms in Hanjiang River basin. J Yunyang Teach Coll. 2005;5:20–4.
19. Li X-Q, Li B-Q, Zhu F-H, et al. Conversation of Yejiashan Cemetery in Suizhou. Hubei Cultural Relics. 2011;11:64–77.
20. Li H-C, Chen J-L, Cui J-F, Wu X-H, Yang Y-L, Huang F-C, et al. Production and circulation of bronzes among the regional states in the Western Zhou Dynasty. J Archaeol Sci. 2020;121: 105191.
21. Guo C-J, Hu T. A preliminary study of the proto-porcelain unearthed from the Western Zhou cemetery of Yejiashan Hubei Suizhou County. Hubei: Hubei Provincial Institute of Cultural Relics and Archaeology; 2013. p. 220–34.
22. Yu Y-B, Cui J-F, Chen J-L, Huang F-C, Guo C-J. The chemical composition and production area of early Western Zhou proto-porcelain unearthed from Yejiashan Cemetery, Suizhou, China. Archaeometry. 2018;60:19–32.
23. Robert T-N, Shadreck C. Archaeological implications of ethnographically grounded functional study of pottery from Nyanga, Zimbabwe. Quat Int. 2020;555:150–64.
24. Jillian MJ, Meaghan MP-B, Sylvestro C, Aurora S, Frank T. It's what's inside that counts: developing a paste group typology in Belize. J Archaeol Sci Rep. 2021;37: 103019.
25. Roxana B, Alexandra T, Iulia I, Daniela D, Bogdan M, Daniele C. Shedding new light on late antique pottery from Histria, Romania. Nucl Instrum Methods Phys Res, Sect B. 2023;528:138–43.
26. Institute of Cultural Relics and Archaeology of Henan province, Pingdingshan heritage administration. Yingguo cemetery in Pingdingshan. 1st ed. Zhengzhou: Elephant press; 2012.
27. Institute of Archaeology Chinese Academy of Social Sciences. Qianzhangda cemetery in Tengzhou. 1st ed. Beijing: Cultural relics publishing house; 2005.
28. Luoyang municipal archaeological team. Western Zhou tombs at Beiyao, Luoyang. 1st ed. Beijing: Cultural riclics publishing house; 1999.
29. Beijing cultural relics research institute. Yan state cemetery of the Western Zhou period at Liulihe. 1st ed. Beijing: Cultural riclics publishing house; 1995.
30. Lu L-C, Hu Z-C. Yuguo Graveyard in Baoji. 1st ed. Beijing: Cultural relics publishing house; 1988.
31. Institute of Cultural Relics and Archaeology of Zhejiang Province, Deqing county museum. Excavations of the mounded tombs in the ducangshan and nanwang mountains in deqing county, Zhejiang province. Archaeology. 2001;10:46–58.
32. Cultural Relics management commission of Quzhou. the proto-celadon in Quzhou, Zhejiang. Archaeology. 1984;1:130–4.
33. Mou Y-K, Mao Z-T. Reconnaissance and trial diggings at the ancient sites and tombs in the southern district of Jiangshan country. Beijing: Cultural Relics press; 1981. p. 57–84.
34. Institute of Cultural Relics and Archaeology of Hubei province, Suizhou museum. Excavation report of Yejiashan M65 in Suizhou, Hubei province. Jianghan Archaeol. 2011;3:3–40.
35. Druc I, Underhill A, Wang F, Luan F-S, Lu Q-Y, Hu Q-T, et al. Late Neolithic white wares from southeastern Shandong, China: The tricks to produce a white looking pot with not much kaolin. Results from petrography, XRD and SEM-EDS analyses. J Archaeol Sci Rep. 2021;35:102673.
36. Guo Y, Jiang Q-Y, Liu Y, Huang W-D, Wu Y-L, Yang Y-M. Provenance analysis of pottery from the neolithic Diaolongbei site, Hubei Province, China by using NAA and petrography analysis. J Archaeol Sci Rep. 2018;21:200–7.
37. Stoltman JB, Yue Z-W, Jing Z-C, Tang J-G, Burton JH, Raudsepp M. New insights into the composition and microstructure of ceramic artifacts associated with the production of Chinese bronzes at Yinxu, the last capital of the Shang dynasty. Archaeol Res Asia. 2018;15:88–100.
38. Yuan C, Zhao C-Q, Wang F, Yuan S-L. Characterization of ceramic from the Early Bronze Age Xinzhai site, Henan Province, China, by using a multi-analytical approach. J Archaeol Sci Rep. 2022;44: 103551.
39. Zhu J, MacDonald BL, Hang T, Zhu Z-W, Glascock MD. Compositional characterization of Zisha clay from the Yixing area (Jiangsu, China) by neutron activation analysis. Microchem J. 2019;147:1117–22.
40. Chang L-H, Chen M-Y, Jin W, et al. Identification manual for transparent mineral thin-section. Beijing: Geological publishing house; 2006.
41. Gao X-L, Zhu L-T, Zhang B, Wu S, Zheng J-M. PIXE and FCA study on the provenance of early celadons unearthed from Nanjing. China J Cult Herit. 2023;62:65–71.
42. Wang E-Y, Xiong Y-F, Zhu Y-B, Wu J-W. Provenance study of ceramic sherds excavated from Qinglong Town site during Tang and Song Dynasties by composition and petrography analysis. J Archaeol Sci Rep. 2021;38:103112.
43. Pareja D, Inanez J, Amara AB, Diaz L, Arana G, Chapoulie R. The Ychsma ceramic provenance from Armatambo, 1250–1532 CE (Lima, Peru). A local or imported production? J Archaeol Sci Rep. 2023;47:103772.
44. Chen T-M, Rapp GJ, Jing Z-C, He N. Provenance study by neutron activation analysis of proto-porcelain in Shang Dynasty. Archaeology. 1997;7:615–28.
45. Chen T-M Jr, Rapp G, Jing Z-C, He N. Provenance studies of the earliest Chinese protoporcelain using instrumental neutron activation analysis. J Archaeol Sci. 1999;26:1003–15.
46. Chen T-M, Rapp GJ, Jing Z-C. Discussion on neutron activation analysis and related problems of primitive porcelain in Shang and Zhou Dynasties. Archaeology. 2003;7:69–78.

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