Ceramics International 43 (2017) 10460–10467

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

Nondestructive characterization of ancient faience beads unearthed from Ya'er cemetery in Xinjiang, Early Iron Age China

Nian Liu[a,b], Yimin Yang[a,b,*], Yongqiang Wang[c], Wanglin Hu[c], Xiaochenyang Jiang[a,b], Meng Ren[a,b], Min Yang[d,**], Changsui Wang[a,b]

[a] Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, PR China
[b] Department of Archaeology and Anthropology, University of Chinese Academy of Sciences, Beijing 100049, PR China
[c] Xinjiang Institute of Cultural Relics and Archaeology, Urumchi 830000, PR China
[d] School of Mechanical Engineering and Automation, Beijing Univ. of Aeronautics and Astronautics, Beijing 100191, PR China

ARTICLE INFO

Keywords:
Faience
Ya'er cemetery
Cultural exchanges
SR-μCT
EDXRF

ABSTRACT

Faience is a kind of ancient ceramic product which was widely found in many areas. Chinese faience appeared in the Western Zhou Dynasty (1046-771BCE), about three thousand years later than western Asia. The sudden and late emergence of Chinese faience implies that its production technology may be influenced by the West. However, little information is known about how the faience productions spread from the West to central China. The Xinjiang Uygur Autonomous Region, located in the northwestern part of China, is one of the most important areas of cultural exchanges between the East and the West since ancient times. The study of faience unearthed in Xinjiang is of great significance to explore the early trade and cultural exchanges between central China and the West. In this paper, Synchrotron Radiation Micro-CT (SR-μCT) and Energy dispersive X-ray fluorescence spectroscopy (EDXRF) have been applied to obtain the information of microstructure and chemical composition of faience beads excavated from Ya'er cemetery (1050-300BCE) in Hami Basin, The Xinjiang Uygur Autonomous Region, China. These faience beads are the earliest faience artifacts in China up to our knowledge and this is the first time to analyze the excavated faience in Xinjiang scientifically. Based on the microstructure of faience beads in CT slices, it is found that two glazing methods, direct application and efflorescence, were used in faience production. Additionally, a cylindrical core made of organic material sustained the faience bead during shaping and firing. According to EDXRF analysis, various glaze recipes have been used to produce these faience beads, possibly indicating different provenance. The characteristics of higher Na_2O/K_2O ratio of faience glaze showed that these faience beads might come from the West. Thus, it is suggested that there was a faience road from Western Asia through Xinjiang to central China about three thousand years ago.

1. Introduction

Faience, which was widely produced in many ancient civilizations, refers to a kind of ancient ceramic with sintered quartz body inside and a vitreous glaze layer outside. According to the present archaeological data, the early faience in the world was firstly found in the Near East at the end of 5th millennium BC, and then appeared in Egypt [1]. Raw materials of faience include quartz, alkali flux, lime and colorants [1]. The shaping methods of faience body include hand-modeling, core forming and moulding on a form. And there are three kinds of glazing technology of faience: direct application, cementation and efflorescence [2].

In China, faience products firstly appeared in the Western Zhou Dynasty (1046-771BCE) and widely found in northern Yellow River Basin including Henan, Shanxi provinces and so on [3]. Ancient faience products in the Western Zhou, which were mainly in the form of bead and tube, often strung together with jade and agate beads. Some scholars argued that the sudden large-scale emergence of faience in the Western Zhou might be influenced by western civilizations [4–6].

Previous studies on Chinese faience mainly concentrated on the recipe of glaze. Gan et al. and Li et al. have used proton induced X-ray emission (PIXE) and scanning electron microscope-energy dispersive spectrometer (SEM-EDS) to analyze the chemical composition of

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[*] Corresponding author at: Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, PR China.

[**] Corresponding author at: School of Mechanical Engineering and Automation, Beijing Univ. of Aeronautics and Astronautics, Beijing 100191, PR China.

E-mail addresses: yiminyang@ucas.ac.cn (Y. Yang), minyang.ndt@buaa.edu.cn (M. Yang).

http://dx.doi.org/10.1016/j.ceramint.2017.05.086
Received 8 May 2017; Accepted 11 May 2017
Available online 12 May 2017
0272-8842/

Chinese faience products from the early Western Zhou to the Warring States Period in Henan province [7,8]. Li et al. has summarized the chemical composition of faience objects obtained by laser ablation inductively coupled plasma atomic mass spectrometry (LA-ICP-MS) and proton induced X-ray emission (PIXE) from Inner Mongolia, Shanxi, Henan and other regions [9]. Gan et al. has revealed the distinction in Na_2O/K_2O between Chinese and Egyptian faience [10]. According to their research, the main chemical composition of Chinese faience in Western Zhou was silica and the content of alkali flux was low as a result of weathering. Compared with western faience, dominant alkali flux of Chinese faience was potassium but western faience always had high sodium and low potassium as flux for the reason that the raw materials of faience in Chinese and Egyptian are plant ash and natron respectively. In faience glaze, copper was firstly used as glaze colorant in ceramic history of China. All above reflect the local characteristics of the Chinese faience. Exceptionally, Zhang et al. found one faience bead which has high soda as flux in Gansu province and considered that the manufacture technology of the soda-enriched faience might be influenced by Egypt [5]. Lei et al. has classified the faience unearthed in China into two groups: soda-enriched faience from the West and potash-enriched produced in central China [6].

Besides chemical composition analysis, the manufacturing process of faience products also has been concerned. In order to get the production technique for faience, various microstructure analysis methods have been adopted. Scanning electron microscopy (SEM) is one of the most widely-using techniques to obtain the microstructure of faience. Tite et al. has put forward criteria to distinguish three kinds of glazing methods of faience [2]. In China, Zhang et al. found that the analyzed faience beads from Gansu province are glazed by efflorescence [5]. Additionally, Yang et al. used synchrotron radiation micro-computed tomography (SR-μCT) to separate the faience, glass and glazed pottery [11]. Gu et al. analyzed the faience beads from Shanxi province by SR-μCT nondestructively and deduced that direct application was the glazing technology of these faience beads [12]. Furthermore, it is deduced that the production process of Chinese faience may be related to bronze smelting and proto-porcelain techniques [13].

The characteristics of Chinese faience and its distinction to the Western faience have been basically clarified. A majority of Chinese faience products have local production features and others may come from the West according to the chemical recipe of glaze. However, it remains unclear how and when the faience products were introduced into China from the West so far. The Xinjiang Uygur Autonomous Region, located in the northwestern part of China, was an important channel for cultural exchanges between the East and the West in ancient times. The faience found in Xinjiang will provide valuable information to trace the technical origin of Chinese faience and new evidences for the cultural exchanges along the Silk Road before the Han Dynasty (202BCE-CE220).

Ya'er cemetery, located in Hami basin, Wupu county, Xinjiang Uygur Autonomous Region, China, is an important Early Iron Age site in Eastern Tianshan Mountain region (Fig. 1). From 2012 to 2013, the archaeologists of Xinjiang Institute of Cultural Relics and Archaeology excavated 490 tombs in Ya'er cemetery. As many as one thousand funerary objects have been found, including pottery, bronzes, ironware, stone tools, carpentry and many other artifacts. Based on the results of radiocarbon dating, it is considered that the main period of Ya'er cemetery lasts from around 1050BCE to 300BCE, corresponding to the periods from the Western Zhou Dynasty (1046-771BCE) to the Warring States period (475-221BCE) in central China. In terms of the characteristics of funeral objects, Ya'er cemetery could be divided into three periods in which period 1 belonged to the transition period from the Tanshanbeilu culture (2000-1300BCE) to the Yanbulake culture (1300-0BCE), but period 2 and period 3 was influenced by the Yanbulake culture (1300-0BCE) [14].

In this study, thirteen faience beads from Ya'er cemetery, which are the earliest faience as the result of radiocarbon dating in China, have been analyzed by SR-μCT and EDXRF to get the information of inner structure and chemical composition. According to these data, the raw materials and fabrication technology of these faience beads would be discussed. Combined with the archaeological background of these beads and research of faience artifacts from other regions, the origin of these faience beads would be deduced and cultural exchanges among Xinjiang and other regions would also be revealed.

2. Material and experiment

2.1. Samples

As shown in Fig. 2, thirteen faience beads, provided by Xinjiang Institute of Cultural Relics and Archaeology, were selected from six tombs of Ya'er cemetery. Among them, only tomb M240 has been directly dated by the radiocarbon dating method. The Age of other five tombs has been deduced in terms of the typological analysis of funeral objects. Colors of the faience samples are mainly blue, green or bluish green and the shapes of these beads are irregular. The detailed information of samples is showed in Table 1.

2.2. Synchrotron radiation micro-CT (SR-μCT) scanning

The faience beads were scanned by SR-μCT at the beamline station BL13W of Shanghai Synchrotron Radiation Facility (SSRF), Shanghai, China. During the experiment, the faience beads were placed on the sample platform. Since the height of the parallel SR X-ray was 4 mm, merely half of the sample could be scanned. The maximal photon flux density appeared at the X-ray energy of 30 keV. The charge-coupled device detector had a space resolution of 9 μm. On the basis of the CT imaging principles, the grayscale of CT slice reflects the object's absorption of X-ray. In general, the heavy elements have high absorption of X-ray, so they look brighter in CT slices. Therefore, according to the grayscale, the body and glaze of the faience beads would be identified and the possible glazing method may be reflected.

2.3. Chemical composition analysis

Energy dispersive X-ray fluorescence spectroscopy (EDXRF) analysis equipment was an XGT-7000 energy dispersive X-ray fluorescence spectrometer from Horiba Ltd, Kyoto, Japan, calibrated using appropriate primary standard Corning-C. The X-ray beam spot diameter was 120 μm. The operation voltage and current of X-ray tube were 30 kV and 208μA respectively and the objects were analyzed under vacuum. The acquisition time is 80 s.

3. Results and discussion

3.1. Microstructure of faience beads

Due to the limited number of the unearthed faience beads from Xinjiang, destructive analysis can't be allowed for intact beads. As an effective nondestructive method, SR-μCT could provide the inner structure of faience [11,12]. The CT slices of eight typical faience beads are presented in Fig. 3, and the glaze layer and body of each faience bead can be clearly observed. The body of faience bead has more pores and the glaze layer is denser.

Based on the microstructure reflected in the CT slices, the scanned faience beads can be divided into group A and group B. The CT slices of faience beads in group A have distinctive grayscale difference between the glaze layer and body. On the contrary, the beads in group B don't have clear grayscale distinction between glaze and body. The majority of the beads belong to group A (Fig. 3a–l). Furthermore, some beads in group A have been glazed both on the outer surface and inner surface of perforation (Fig. 3a–d, i–l), and others merely have glaze layer on the outer surface (Fig. 3e–h). Only two beads (Y2, Y3) belong to group B (Fig. 3m–p).

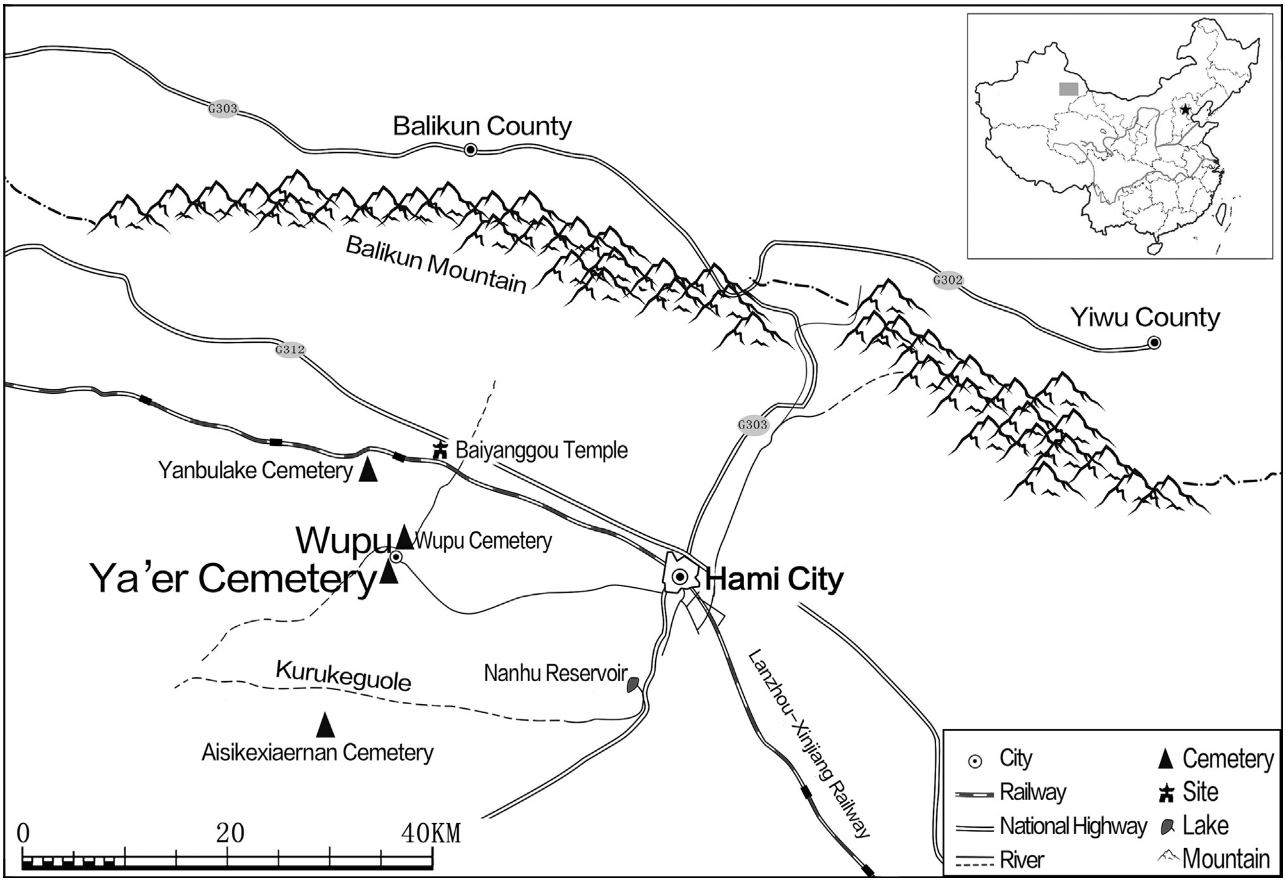

Fig. 1. The location of Ya'er Cemetery.

Through the above analysis, the inner structure of faience beads being divided into two groups indicates that these faience beads may be glazed by two different methods. According to the previous studies, three kinds of glazing methods, namely direct application, cementation and efflorescence, can be differentiated by the grayscale distinction and thickness of glaze layer in SR-μCT slices [12,15].

In the previous laboratory replication study, the relationship between the variations of grayscale in CT slices and the glazing methods has been proved. When using the efflorescence glazing method to produce the faience, there is no significant grayscale difference between the body and glaze layer in CT slices. However, when producing the faience by direct application or cementation glazing method, the region of the glaze layer in CT slices is brighter than that of the body and there is a clear boundary between them [15]. As for the mechanism of these experimental results, researchers held the view that the distribution of chemical composition in faience varies from different production technology and components of glazing mixtures used. In the efflorescence glazing method, chemical composition profiles of glass phase from interparticle glass to glaze layer shows a decrease of heavy elements, such as Cu, Ca, but soluble salts, such as soda, migrate to the surface in drying. Conversely, for cementation and direct application glazing, heavy elements are more in glaze layer than in the body [15,16].

As for the production process of faience beads analyzed in this study, showed in Fig. 3, the glazing method of samples in group A, which has apparent grayscale distinction between body and glaze layer in CT slices, is deduced to be the cementation or direct application. On the basis of the previous replication experiment, the thickness of glaze layer can be used to differentiate the possible fabrication technique of faience products [15]. The direct application glazing method is characterized by the variable glaze thickness, but the glaze thickness of cementation faience is always uniform. Owing to the sideways run of glaze, the glaze at the base or rim of faience products glazed by the direct application method is much thicker than the glaze in other positions of the objects. For the cementation glazing method, the fused cementation mixture remained after firing would be wiped off and grinding marks would be left [12]. As shown in Fig. 3a–l, the glaze thickness of the beads in group A is variable and the glaze at rim is obviously thicker. There is no grinding mark in the surface of faience beads in group A. All above analysis shows that the beads in group A are glazed by the direct application method. In addition, the beads in group B (Fig. 3m–p) should be produced by the efflorescence glazing method owing to the homogeneity of grayscale between the body and glaze layer of faience in CT slices.

In addition, as showed in Fig. 3, the inner walls of most faience beads are straight and there is no clay or metal sintered in the perforation, indicating that a cylindrical core of organic material sustain the faience bead during shaping and firing, namely the core-forming method.

3.2. *The chemical recipe of glaze*

The chemical compositions of faience glaze are showed in Table 2, and the glaze recipe of faience beads from Ya'er cemetery is various. The Na_2O/K_2O ratio is an effective index to determine the source of faience between China and the West. Some scholars believe that when Na_2O/K_2O ratio is more than one, the faience object should be imported from the west. On the contrary, it is suggested that the faience product may manufacture locally in China if the Na_2O/K_2O ratio is less than one [10]. Accordingly, these faience beads are classified into two types: only bead Y2, Y10 and Y12 belong to type I ($Na_2O/K_2O < 1$), and the other ten beads with high soda and low potash belong to type II ($Na_2O/K_2O > 1$). The Na_2O+K_2O content of faience beads in Type I and some in Type II is lower than 3%, probably

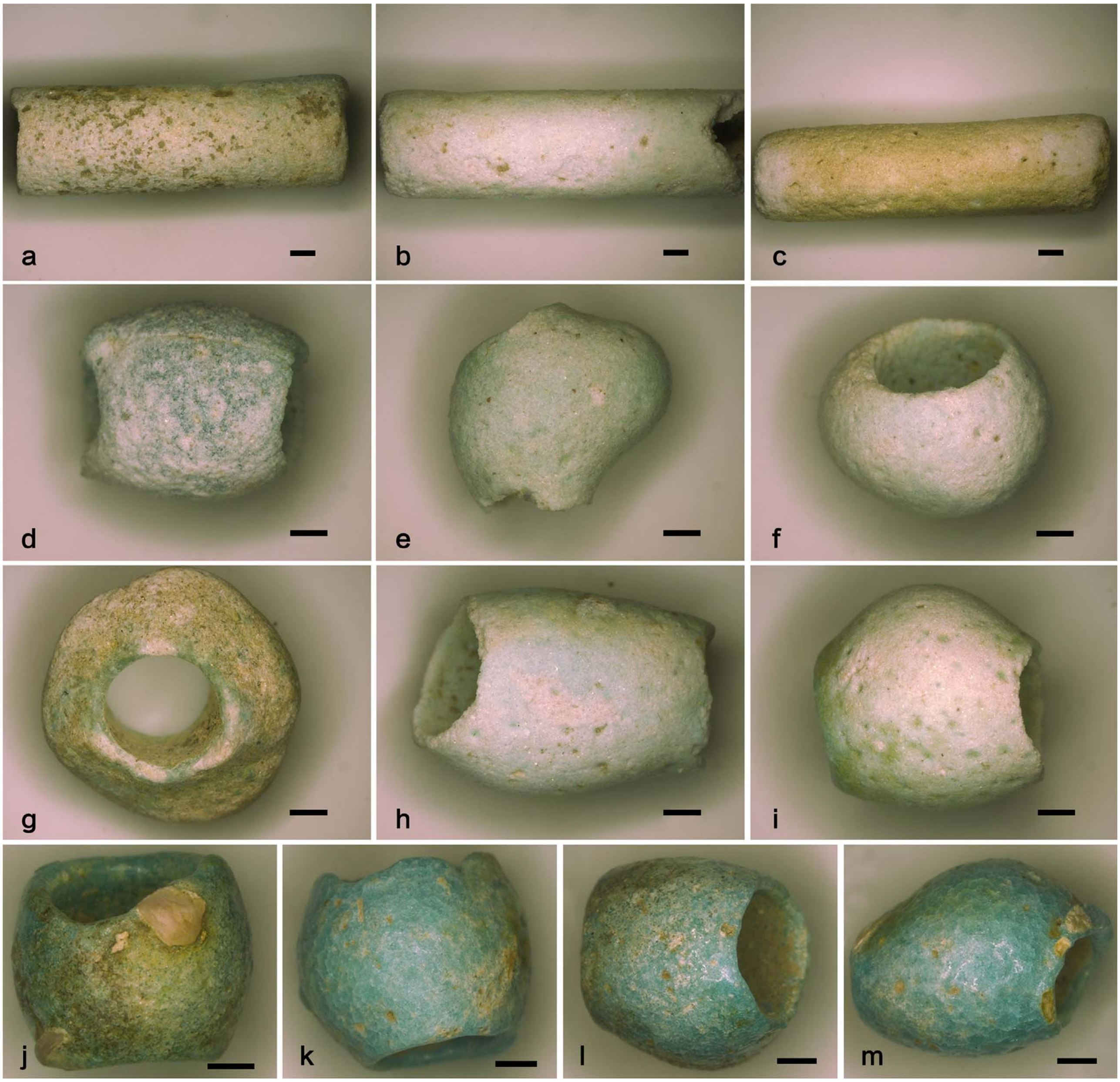

Fig. 2. Photographs of the faience objects (a-m: sample Y1-Y13. The scale bar is 1 mm.).

due to the lost of alkali flux result from serious weathering, thus the composition data of these samples may not be consistent with the original glaze recipe [17]. Whatever, soda-enriched faience occupied the dominant position in all the faience beads from Ya'er cemetery. Thus, the faience beads in Ya'er cemetery may be imported from the West or be locally produced and influenced by the West in production technology.

In addition, the content of other chemical elements among the faience beads also has quite a few diversities. The content of MgO in most of samples is nearly 0% except sample Y3. It is suggested that the raw material of alkali flux for the most of faience beads in Ya'er cemetery may be natron. The colors of most of analyzed faience beads are blue-green with copper as the colorant. The content of CuO in the beads from tomb M240 is about 3%, which is higher than that in the beads from other tombs. As shown in Fig. 2, the faience beads from M240 have a higher degree of vitrification and deeper color than other beads, which may result from the higher content of CuO. Moreover, PbO has been detected in all of the faience samples but the contents of that are lower than 1% except for bead Y7. Ya'er cemetery was influenced by Tanshanbeilu culture (2000-1300BCE) and Yanbulake culture (1300-0BCE) in Hami basin, Xinjiang. According to the past research of archaeometallurgy, the types of bronze ware in Tanshanbeilu culture and Yanbulake culture contained tin bronze, arsenical bronze and some kinds of ternary copper alloy [18]. Nevertheless, there was no tin or arsenic that has been found in these faience samples, therefore bronze should not be used in the faience manufacture. Accordingly, copper ore may be the possible source of the colorant for the tested faience beads and the small amount of lead may be impurities from copper ore. As for the sample Y7 with exceptional high lead content, confirmed by the uneven distribution of brighter regions in the glaze layer in CT slice (Fig. 3i), the lead may be an accidental additive by ancient craftsmen or may be brought from a lead-rich copper ore. It is not clear whether the specific lead indicates the possibility of local production of the faience beads. Further lead isotope analysis may give more evidence for this question.

Overall, the recipes of faience beads unearthed in Ya'er cemetery were diverse and complicated, which suggested that these faience samples might have multiple sources. As a significant hub of cultural

Table 1
The archaeological information of Ya'er faience.

Sample	Tomb	Date	Detailed description
Y1	2012HWYM317:2	Tianshanbeilu culture	Tube, light blue outside with tiny white particles; length, 1.45 cm; diameter, 0.49 cm.
Y2	2012HWYM33:1	Yanbulake culture	Tube with white outside, part of surface in blue color; length, 1.65 cm; diameter, 0.48 cm.
Y3	2012HWYM61:3	Yanbulake culture	Tube with white surface; length, 1.52 cm, diameter, 0.42 cm.
Y4	2012HWYM325:2	Tianshanbeilu culture	Long oval bead, light blue outside with tiny white particles; length, 0.65 cm, diameter, 0.58 cm.
Y5	2013HWYM473:3	Tianshanbeilu culture	Irregular bead, light blue-green outside with tiny white particles; length, 0.55 cm, the maximum diameter, 0.65 cm.
Y6	2013HWYM473:3	Tianshanbeilu culture	Approximate spherical bead, light blue-green outside with tiny white particles; length, 0.45 cm, the maximum diameter, 0.68 cm.
Y7	2013HWYM473:3	Tianshanbeilu culture	Bead like a flat abacus, light blue-green outside with tiny white particles; length, 0.5 cm, diameter, 0.72 cm.
Y8	2013HWYM473:3	Tianshanbeilu culture	Irregular bead, light blue-green surface with tiny white particles; length, 0.61 cm, the maximum diameter, 0.66 cm.
Y9	2013HWYM473:3	Tianshanbeilu culture	Bead like a jujube pit, light blue-green outside with tiny white particles; length, 0.83 cm, diameter, 0.6 cm.
Y10	2012HWYM240:9	Tianshanbeilu culture (1050–910BCE)	Irregular bead with bluish green surface; length, 0.4 cm, the maximum diameter, 0.54 cm.
Y11	2012HWYM240:9	Tianshanbeilu culture (1050–910BCE)	Approximate spherical bead, bluish green outside; length, 0.41 cm, diameter, 0.5 cm.
Y12	2012HWYM240:9	Tianshanbeilu culture (1050–910BCE)	Similar to Y11; length, 0.4 cm, diameter, 0.51 cm.
Y13	2012HWYM240:9	Tianshanbeilu culture (1050–910BCE)	Long oval bead with blue-green outside; length, 0.61 cm, diameter, 0.54 cm.

communication between the East and the West, a large number of artifacts from different cultures has been excavated in Xinjiang. Therefore, it is fairly possible that the faience beads with different glaze recipe in Ya'er cemetery may come from different areas.

3.3. Cultural exchanges

For the provenance study of the analyzed faience beads, typical chemical compositions of faience products from central China, Egypt, Mesopotamia and Indus respectively have been randomly selected to compare with the glaze recipe of Xinjiang faience, which was listed in Table 3. Scattered diagram has been applied to show the Na_2O/K_2O ratios of faience samples from different regions (Fig. 4).

The chosen chemical composition data of central China's faience contained samples from Shanxi, Henan and Inner Mongolia. In contrast to central China's faience, Na_2O/K_2O ratio of Xinjiang faience are mostly more than one, which indicates that there are quite different flux systems between Xinjiang faience and central China's faience. It is suggested that the production process of Xinjiang faience either was affected by the West rather than central China or may be import from the West.

In order to ascertain the provenance of Xinjiang faience, the chemical compositions of faience from Egypt, Mesopotamia and Indus published in previous study were used for comparison. From the scattered diagram in Fig. 4, the feature in glaze recipe of Mesopotamian faience shows the high content of potassium. Kaczmarczyk once noted that the average K_2O content of the Mesopotamian faience was up to 5% based on surface XRF analysis made in air [23]. However, none of the K_2O content of Xinjiang faience samples is more than 1%. Thus, it is hardly possible that Mesopotamia is the provenance of Xinjiang faience. The characteristics of Na_2O/K_2O ratios for Xinjiang faience showed in Fig. 4 are closer to Egyptian faience and Indus faience mostly.

In combination with the archaeological background, the earlier period of Ya'er cemetery belonged to the transition period from Tanshanbeilu culture to the Yanbulake culture and the later two periods of Ya'er cemetery belonged to the typical Yanbulake culture in the Eastern Tianshan Mountain region. The Eastern Tianshan Mountain region, which is centered in Hami basin, has been the key area of East-West cultural communication in ancient times. According to the anthropological investigation of human skeletons, in the first half of the 2 millenniums BC, the residents in Hami basin represented by Tianshanbeilu cemetery mainly belonged to the Mongolia ethnic groups migrating from the East, but also found the Western European racial features [24]. Painted pottery from the East dominated the pottery system of the Tanshanbeilu cemetery, and with the painted pottery came the original millet agricultural factors. From the early Bronze Age, metallurgical technology, wheat planting technique, and cattle and sheep domestication spread from the West Asia through the Central Asia steppe and the Western Tianshan channel into the eastern Tianshan mountains [25]. There was also a kind of cylindrical pottery in prehistoric culture of Hami basin, which is obviously relevant to the embossed pattern pottery popular in the western steppes of Eurasia [26]. The adobe was used to build the tomb and the prevalent flexed-body burial style in Tianshanbeilu cemetery derived from the West. After the first millennium BC, corresponding with the late Bronze Age, Western European racial occupied a dominant position in Hami basin [27]. During this period, Hami basin came into the period of Yanbulake culture. Yanbulake culture is a kind of regional archaeological culture which not only inherited the cultural tradition of the Bronze Age represented by the Tianshanbeilu cemetery in the Hami basin, but also absorbed the impact of other neighboring regional cultures. It is difficult to find the direct evidence of cultural exchanges among Yanbulake culture and the remote western regions. At present, only Barber pointed out that ancient textiles and textile technology from Kroraina, Qiemo and Hami Yanbulake culture were similar to those from Egypt, Babylon, etc [28]. The textile technology seemed to have spread from the Near East to the northern Eurasian Steppe, and then from the Altai Mountains to the south, finally entered into the Tianshan Mountain. This line is consistent with the Bronze Road put forward by Chinese scholars in recent years [25]. Direct evidence of communication between Hami basin and Southern Asia in the prehistoric period has not yet been found up to date.

From the above discussion, it is most likely that faience beads in Ya'er cemetery were introduced from the West. This is not to say that there is no possibility of other sources for faiences in Xinjiang. As already mentioned, the analysis of production technique and chemical composition data indicates that there may be a variety of sources of these faience beads. According to previous study, the production process of Gansu faience may be influenced by Egypt [5]. Gansu province, which is adjacent to Xinjiang, is also an important region in ancient Silk Road. There were already frequent trade and cultural exchanges between Xinjiang and Gansu more than three thousand years ago. Painted pottery of central China spread into Hami basin

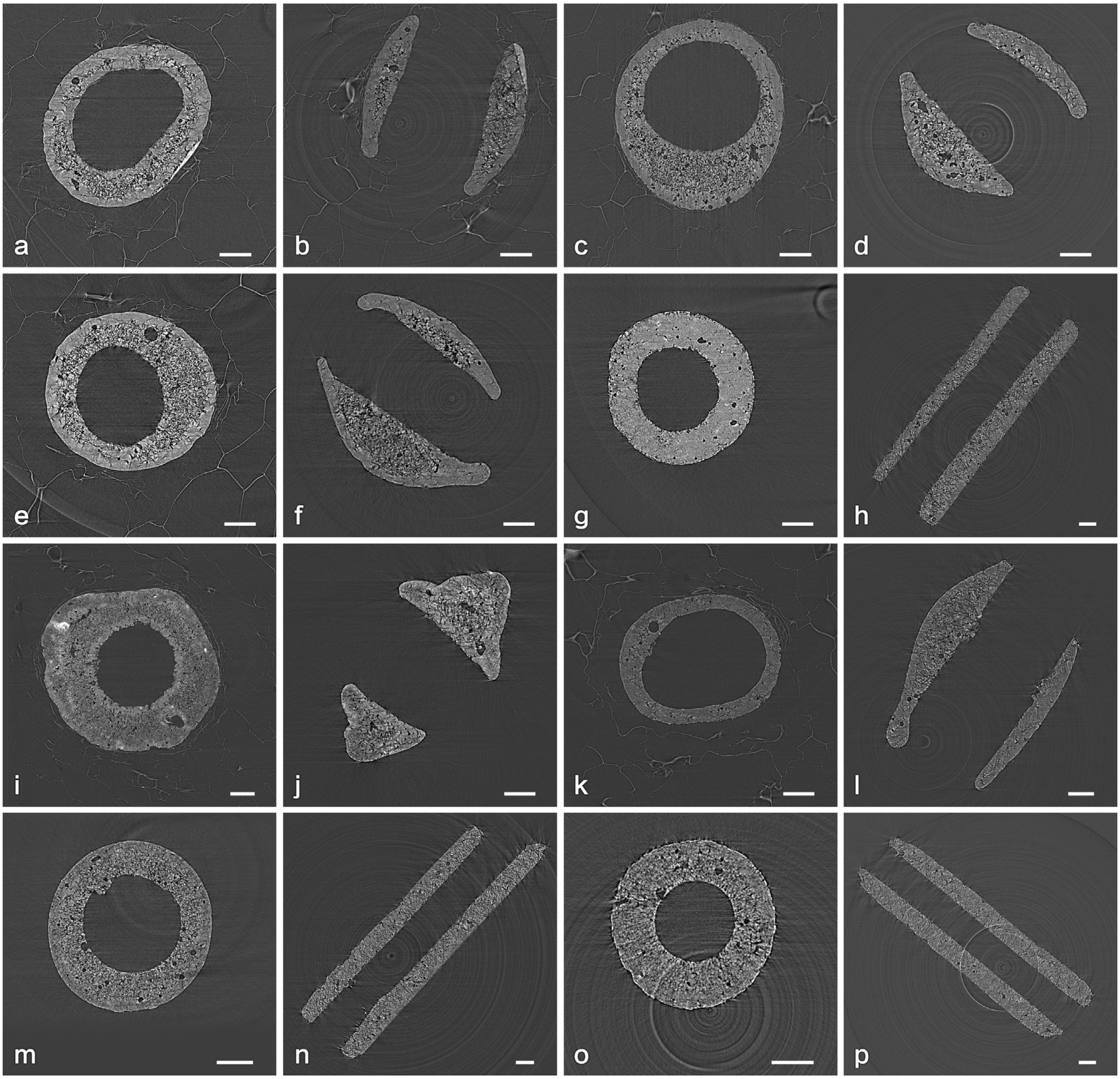

Fig. 3. The CT slices of eight faience beads (a: the cross section of bead Y11; b: the longitudinal section of bead Y11; c: the cross section of bead Y12; d: the longitudinal section of bead Y12; e: the cross section of bead Y13; f: the longitudinal section of bead Y13; g: the cross section of bead Y1; h: the longitudinal section of bead Y1; i: the cross section of bead Y7; j: the longitudinal section of bead Y7; k: the cross section of bead Y9; l: the longitudinal section of bead Y9; m: the cross section of bead Y2; n: the longitudinal section of bead Y2; o- the cross section of bead Y3; p: the longitudinal section of bead Y3. The scale bar is 1 mm.).

Table 2
Chemical composition of the glaze of the faience beads from Ya'er cemetery.

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	MnO	Fe_2O_3	CuO	PbO	Na_2O/K_2O
Y1	1.93	0	2.12	90.4	2.1	0.23	0.15	0.3	2.05	0.02	0.22	0.42	0.1	6.43
Y2	0	0	3.46	90.4	2.93	0.13	0.07	0.15	2.18	0.01	0.12	0.54	0.03	0
Y3	2.71	3.76	1.84	88.54	0.59	1.2	0.47	0.3	0.53	0	0.16	2.34	0	9.03
Y4	0.88	0	3.77	92.9	0.25	0.09	0.04	0.15	0.51	0.01	0.21	0.64	0.58	5.87
Y5	4.04	0	1.6	90	0.71	0.53	0.49	0.07	1.96	0	0.14	0.4	0.03	57.71
Y6	4.07	0	1.91	88.5	0.45	0.68	1.19	0.19	1.15	0	0.22	1.55	0.08	21.42
Y7	1.81	0	1.97	85.3	3.17	0.08	0.49	0.28	1.79	0	0.24	1.39	3.54	6.46
Y8	2.56	0	2.44	91.5	0.39	0.4	0.71	0.16	0.98	0	0.15	0.72	0.02	16
Y9	3.86	0	1.96	87.8	2.99	0.44	0.56	0.19	1.57	0	0.14	0.46	0.02	20.32
Y10	0	0	4.27	77.73	0.44	0.94	0.43	0.65	10.36	0.15	0.99	3.88	0.16	0
Y11	2.72	0	2.61	88.12	1.39	0.1	0.25	0.37	1.32	0	0.11	2.93	0.07	7.35
Y12	0.04	0.01	1.41	93.7	0.43	0	0.21	0.22	0.55	0.03	0.1	3.15	0.2	0.18
Y13	0.5	0	1.41	92.2	0.68	0	0.27	0.2	1.43	0	0.08	3.21	0.04	2.5

Table 3
Typical chemical compositions of ancient faience glaze from different regions (wt%).

	Period	Si_2O	Al_2O_3	CaO	MgO	Na_2O	K_2O	FeO	CuO	Na_2O/K_2O
Xingjiang faience	1050-300BCE	85–94	1–4	0.5–10	–	0.5–4	< 1	< 1	0.4–4	2.5–58
Central China's faience [19–22]	1100-476BCE	70–94	0.3–4	0.1–2	< 1	0.3–3	0.3–15	< 1	0.1–8	< 1
Egyptain faience [1]	2040-712BCE	64–84	0.2–1.3	0.3–5	< 1	4–13	1–5	0.2–3	3–10	2–4
Mesopotamian faience [1]	3000-2200BCE	70–90	2–17	0.4–7	1–2	0.4–9	0.7–9	0.3–3	0–5	0.3–2
Indian faience [1]	2800-1900BCE	71–81	3–12	0.5–4	0.3–3	6–9	1–3	1–7	0.1–3	2–5

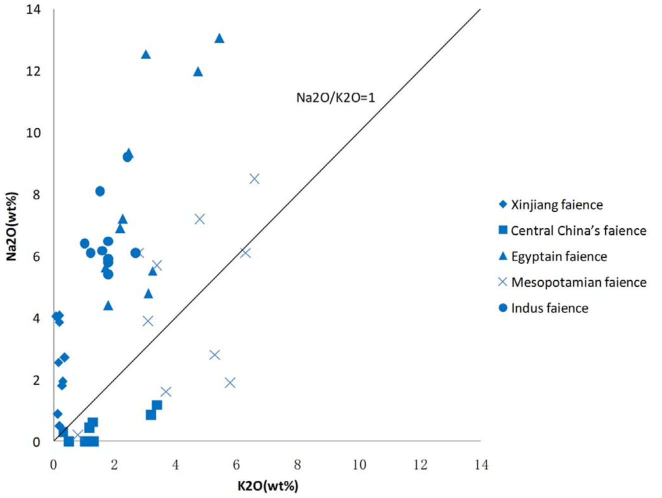

Fig. 4. Na_2O/K_2O scattered diagram of faience respectively from Xinjiang, central China, Egypt, Mesopotamia, and Indus [1,19–22].

through the Hexi Corridor in Gansu [29]. It is a common view that the production technology of bronze in China spread from the West. Tin bronze occupied the dominant position among the bronze wares unearthed in the Eastern Tianshan mountain region with a large proportion of arsenic bronze. As one of the earliest copper alloys being produced and used by human beings, arsenic bronze appeared at the beginning of 4th millennium BC in the Western Asia. To 3rd millennium BC, arsenic bronze has developed into the main bronze type in some regions of Caucasus and Central Asia. To the first half of 2nd millennium BC, the center of arsenic bronze production has been formed in the Ural mountain area in the middle part of the Eurasian Steppe, and there were some evidences of the eastward spread of arsenic bronze [30,31]. Most of the early arsenic bronze wares in ancient China were excavated from the Eastern Tianshan mountain region centrally. Moreover, arsenic bronze were also generally found in Siba culture (1900-1300BCE) and Qijia culture (2000-1900BCE) in Gansu province, and there were a few findings in Erlitou Site (1750-1500BCE) in central China. Thus, there was a decreasing trend of the quantity and proportion of arsenic bronze wares in China from the west to east, and the date of the arsenic wares in western China were earlier than that unearthed from the eastern China [25]. Combined with the past study of archaeological typology, it has proved that there was a clear spread route of bronze technology from the West through Xinjiang and along Hexi Corridor finally into central China which was called Bronze Road by Chinese archaeologists [25]. It is demonstrated that the manufacture technology of Xinjiang faience may be influenced by the West in this study and the soda-enriched faience also has been found in Gansu and Shanxi province, which indicates that there was a spread route of faience similar to the Bronze Route (Fig. 5).

When the faience from the West arrived in central China, the ancient Chinese craftsmen made a large amount of imitation based on the advanced proto-porcelain technique in Western Zhou Dynasty. Besides the distinction in chemical composition, the function of faience beads was also different between faience beads from central China and Xinjiang. As a part of hand chains or necklaces, a majority of faience beads in Ya'er cemetery were unearthed from civilian tombs. By contrast, faience beads in central China often strung together with jade and agate beads and mostly excavated from high-specification tombs as a status symbol [32].

4. Conclusion

In this study, fabrication technology and chemical compositions of the faience beads excavated from Ya'er cemetery have been revealed nondestructively by SR-μCT and EDXRF. Firstly, it is concluded by the observation of CT slices that most of faience beads in Ya'er cemetery were glazed by direct application method and merely two beads were glazed by efflorescence method. During the course of shaping and firing, a cylindrical core made of organic material should be used to support the faience bead. Furthermore, the diversity of faience chemical composition in Ya'er cemetery indicates the various sources of faience. A majority of faience in Ya'er cemetery was associated with high sodium and low potassium.

By comparing Na_2O/K_2O ratios of faiences in different regions, combined with the archaeological background of the sites, most of faience beads in Ya'er cemetery probably introduced from the West. As is known to all, Silk Road was officially opened in Han dynasty (206BCE-CE220), which linked the trade and cultural communications on the Eurasian continent. In recent years, scholars gradually attached importance to the study of Silk Road before Han dynasty. Large amount of evidences demonstrated that the East and the West had already begun to have trade and cultural exchanges before the Han Dynasty. The present study of faience in the early Iron Age Xinjiang pointed out a possible technology source of Chinese faience and described a probable spread route of faience. The soda-enriched faience in central China may be imported from the West through Xinjiang, and the Chinese faience technique may be influenced by the West. The study on Xinjiang faience provides new evidences to the research of cultural communication on pre-historical Silk Road.

Due to the limitation of the samples, the specific provenance of Xinjiang faience is not completely determined, and it needs further detailed study and more archaeological findings. In any case, the scientific analysis of the excavated faience in Xinjiang was carried out for the first time, which provides some thoughts and directions to explore the technical source of Chinese faience. SR-μCT has been confirmed to be a useful method to deduce possible production process of faience nondestructively by providing valuable information on the microstructure of faience once again.

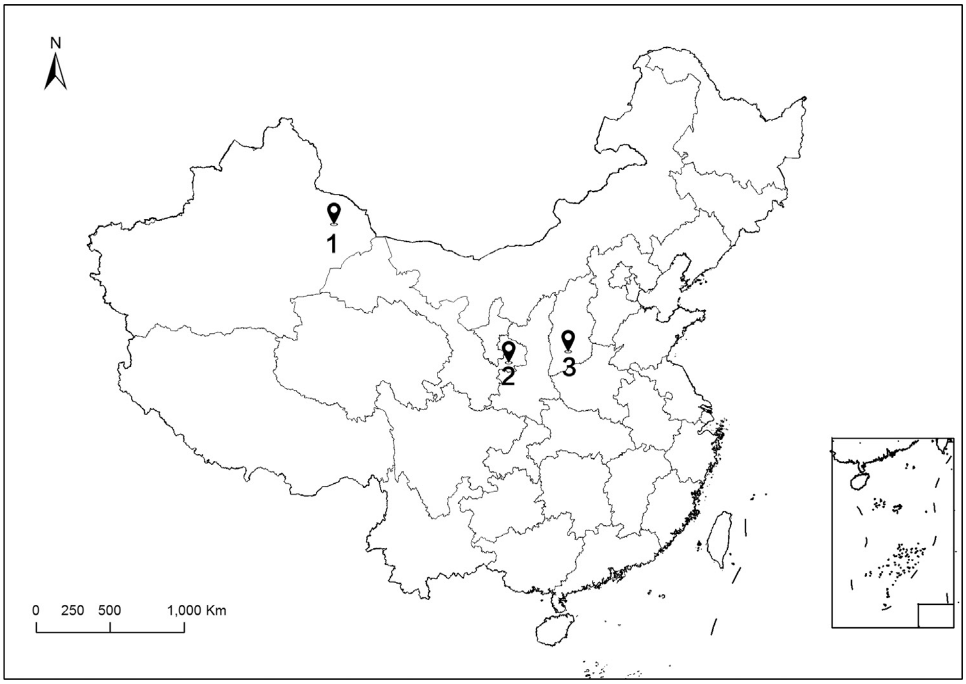

Fig. 5. A map showing the sites where the soda-enriched faience objects are unearthed in China (1: Ya’er Cemetery in Xinjiang; 2: Yujiawan Cemetery in Gansu; 3: Tianma-Qucun in Shanxi).

Acknowledgements

This work was supported by the National Development Project of Significant Scientific Instruments in China (2014YQ240445) and Youth Innovation Promotion Association of CAS (2013281). We are particularly grateful to associate professor Jianfeng Cui of Peking University for providing the EDXRF analysis equipment.

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