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The Qianlong Emperor's order: scientific analysis helps find French painted enamel among Palace Museum collections

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Abstract

Painted enamel holds special significance in the study of the history of Chinese ceramic and glass. Painted enamel also represents interesting evidence of cultural communication between China and European countries. In the past, studies on painted enamel have mainly focused on archival research. Although modern scientific techniques have complemented research on enameled artifacts, the quality of the samples has usually been inferior. This study combines scientific analysis and archival work to explore four similar pots from the Palace Museum collection, along with the specific documentation information attached to them. Raman spectra, XRF and CT scanning were applied to compare the four pots. Results show that one of the pots is made of gold and use cassiterite and Naples yellow as opacifier and pigments, this pot bears the hidden hallmarks of a Parisian goldsmith, providing direct evidence that the pot was made in France in 1783. The other pots are proven to have been made in China, which are made of copper gilded with gold and use lead arsenate and lead tin yellow as opacifier and pigments. This work reveals a previously unnoticed route by which enamel artifacts reached the Chinese court.

Keywords: Painted Enamel 1, French Hallmarks 2, Cultural Exchange 3, Noninvasive analysis

Introduction

Painted enamel has a unique significance in the development of ceramic and glass craftsmanship during the Qing Dynasty in China. As a brand-new glass craft at that time, painted enamels first began to be widely produced during the 15th century in Italy, as well as in the Netherlands [1, 2]. The technique of painted enameling reached its peak development in Limoges in southwestern France during the 16th century [3–5]. The art of painted enamel was not only appreciated by the upper class in Europe but was also sought after by emperors in the East, especially Emperor Kangxi (1654–1722) of the Qing Dynasty, who was the first emperor to own painted enamel artifacts in China. Emperor Kangxi was deeply fascinated by painted enamels when first time he received tribute from French Jesuit missionaries in 1685. From that time on, Emperor Kangxi regarded the development of painted enamel as a national project and directly presided over the selection of talented craftsmen and the standards of production. He recruited missionaries and local ceramic manufacturing craftsmen to help him successfully produce painted enamel objects bearing Chinese characteristics and transmitted his love of painted enamel to the Qing emperors who came after him. At the time, this new process and the raw materials and glaze-making skills it involved had a significant impact on the production of local-colored ceramics in China.

Although the development of painted enamel in China is recent, complex factors need to be considered to understand its production process [6, 7]. Therefore, the use of modern analyses and detection technology is increasingly necessary, and many scholars have studied Chinese painted enamel in different periods. The

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first scientific analysis and detection of painted enamel in China was carried out in 1980 by Fukang Zhang and Zhigang Zhang [9]; thirty years later, the Palace Museum was able to analyze three samples of painted enamel fragments [10]. Meanwhile, the Museum of Fine Arts, Boston started the scientific analysis of three pink fragments to study the Chinese *famille rose* in 1982 [11]. In 1986, William Kingery and Pamela Vandiver from MIT [12] continued the analysis of the four overglazed fragments to verify the test results produced by the Boston Art Museum. In 1999, the Victoria and Albert Museum organized a large-scale analysis of China's overglazed ceramics, including 48 wares [13]. The latest research using modern science and technology to study painted enamel was carried out by Dr. Philippe Colomban at Sorbonne Université, France. In cooperation with many museums, more than 30 pieces of overglazed and painted enamel were analyzed by using portable Raman spectrometer detection [14, 29].

To date, scholars working on Chinese painted enamel and the glazed ceramics of the Qing Dynasty have revealed trends in the development of Chinese overglaze coloring and the typical distinguishing characteristics of Chinese and foreign craftsmanship. However, these studies have been limited. First, only a few studies have focused on enamel artifacts that are entirely intact [9, 29], and most studies on painted enamel have examined only ceramic fragments as their samples. Ceramic fragments are not as representative because it is almost impossible to find historical archives to obtain specific chronological information about them. This leads to the second limitation, which is that past research has mainly focused on the overall history of the development of overglazed technology in ceramics or painted enamel. However, the chronological information that is summarized in the scientific results is usually obscure, which means that it is difficult to discern the exact year when one symbolic glaze composition was put to use or abandoned. Third, this type of research needs appropriate samples, both in quantity and in quality. Few large collections of painted enamel, whether on metal or ceramic bodies, are available for scientific analysis.

The Palace Museum located in Bejing China collect a large number of painted enamels inherited from the court of the Qing Dynasty. These collections include painted enamel products from different production workshops in different periods of the Qing Dynasty in China. The scientific analysis and detection work done on these treasures will play a substantial role in promoting research about the dissemination, development and understanding of Chinese painted enamel technology. In this research, four similar painted enameled pots were analyzed using a series of nondestructive methods. The opportunity to bring together four similar pots that were produced during the same era is a rare one. However, from the appearance and quality of the pots, it can be inferred that they likely were produced in different workshops. The experimental results reveal differences in the origins of the raw materials used, and the artifacts themselves reveal information that directly proves that one of the pots was produced in France and stored in the Forbidden City. Moreover, valuable relevant records about the production of these pots were found in the archives; according to these records, these pots do not exist in isolation but are connected to each other. The results of the analysis, combined with information from the Qing court archives, describe the compelling history of painted enamel production during the Qing Dynasty.

Materials and methods

Artifacts

In this research, four metal pots were chosen as the study objects, and their pictures are shown in Fig. 1. All four pots are in the collection in the Palace Museum. They are very similar in appearance. The pot bodies are flat and square with rounded corners. For all four, the mouth, lid, and feet are in the shape of chrysanthemum petals. The bodies of the pots are made of yellow enamel glaze on which a chrysanthemum pattern of folded branches has been painted. Furthermore, oval metal stripes are embossed on all sides, and the interior is painted with large chrysanthemum patterns. The bottom of the pots is covered by a white glaze, and the blue double circle in the center is marked with the four-character regular script "Qianlong Nianzhi", which indicates that the pots date back to the eighteenth century. It is worth noting that the script "Qianlong Nianzhi" was found on all four pots. However, the four pots show obvious differences in size, glaze color and painting techniques. For the convenience of discussion, an alphabetical classification was used to refer to the four pots. In pot A (Fig. 1A inset image), a few words written in red appear just above the foot edge; this can be seen after zooming in. It is actually a Western craftsman's name "Coteau". This signature is most likely that of Joseph Coteau (1740–1801), a famous enamel painter in 18th-century France [8].

Instrument

Raman analyses were performed on a RENISHAW InVia2000 confocal Raman spectrometer equipped with an external optical fiber probe. The excitation line of the laser ($\lambda ex = 532$ nm) was focused through a $50 \times$ long working distance objective onto the samples. The power at the samples was kept never exceeding 1.5 mW to avoid any thermal damage. Elemental analysis was performed on a Bruker ARTAX X-ray fluorescence

Fig. 1 Four pots as research objects. They will be cited in the following text as pot **A**, pot **B**, pot **C** and pot **D**. They were all made during the Qing Dynasty of the Qianlong Emperor

spectrophotometer. The experimental conditions were as follows: A Rh X-ray source was used at 50 kV and 200 μA; the spot size was set as 70 μm to guarantee a high spatial resolution; the time for a single test was 120 s, and each sample was tested 3 times. A Yxlon 600 kV CT was used to scan the inner structure. The experimental voltage was 220 kV; the current was 0.31 mA; there was no filter, and the data reconstruction was carried out using VG Studio max3.0 software.

Results

Metal matrix

The XRF analysis results of the metal matrix in the four pots are shown in Table 1. Here, the element analysis was performed using the XRF method. This method is only a semiquantitative analytical progress and has two limitations. The first is that light elements such as Mg, Na, B or even Al cannot be measured accurately. The second limitation is that XRF measurements are not precise about the volume analyzed, which is very different depending on the element measured. The penetration depth of the light elements (Mg, Al, Si, K, and Ca) is close to the surface, while it is more than several hundreds of μm for heavier elements such as lead (Pb) and gold (Au) and several mm for tin (Sn) and antimony (Sb) [31]. In this paper, only the apparent compositions were discussed.

The element analysis results show that pot A features obvious differences when compared to the other pots. The metal parts of Pot A contain 91% gold, 4.3% copper and 4.1% silver on average, and it is basically a golden

Table 1 Metal matrix element detection results in the four pots

	Pot A(wt%)				Pot B(wt%)				Pot C(wt%)				Pot D(wt%)			
	Cu	Zn	Ag	Au	Cu	Zn	Au	Hg	Cu	Zn	Au	Hg	Cu	Zn	Au	Hg
Lid	3.1	0	3.3	93.6	29.7	2.4	58.3	9.6	51.3	0.5	42.6	5.7	48.4	2.9	44.3	4.4
Body	4	0	3.4	92.6	24.9	0.8	63.3	11	11.2	0.6	74.9	13.3	34.9	0.9	56	8.3
Ring	3.3	0	4.7	92.1	40.9	2.2	48.5	8.3	59.8	2.5	32.6	5.2	37.9	2.2	51.9	8
Bottom	7.4	1.1	5.4	86.1	53.7	0.2	39.6	6.5	53.2	2.3	38.2	6.3	48.9	0	44.1	7
Average	4.4	0.3	4.3	91.1	37.7	2	51.7	8.7	44.8	1.3	46.7	7.3	57.2	1.5	35.9	5.4

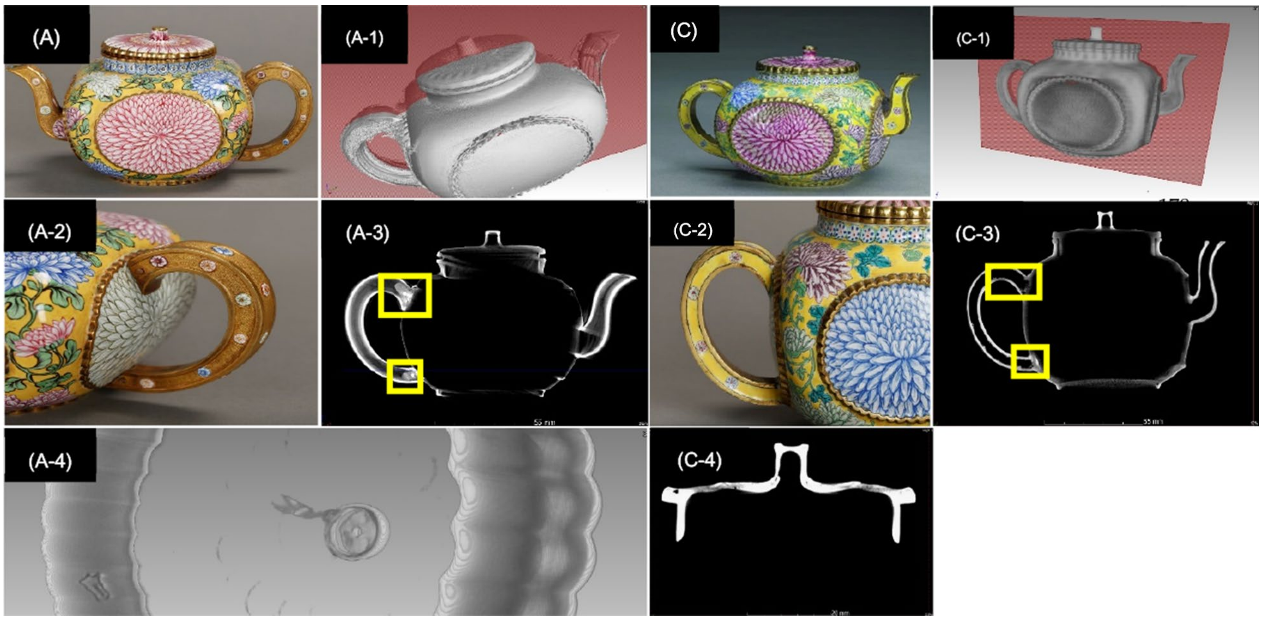

Fig. 2 CT scanning results for the four pots. (**A**) shows pot **A** and its corresponding overall CT (**A-1**). Pots **B**–**D** share similar structural characteristics, so in (**C**), pot C is chosen as the representative. (**C-1**) is the overall CT result for pot C. (**A-2**) is a detailed picture of the handle in pot **A**. (**A-3**) is the CT scanning picture of the handle in pot **A**. (**C-2**) is a detailed picture of the handle in pot **C**. (**C-3**) is the CT scanning picture of the handle in pot C. (**A-4**) CT scanning of the lid in pot A, while (**C-4**) CT scanning of the lid in pot **C**

painted enamel pot. The detection of Hg elements supports that while the main metal matrix for the other pots is copper, the surface of the copper is gilded with gold; in ancient China, it is common to use gold amalgam to gild metal with gold. In this case, craftsmen usually cover the metal with a mixture of Hg and Au; after heating, the Hg evaporates, and gold remains on the surface.

Structure

To comprehensively investigate the structure of each painted enamel pot, X-CT was performed (Fig. 2A, A-1, C, C-1). CT scanning was necessary because it could be seen from the outside that there were differences in the structures of the four pots, for example there was a small screw on the handle of the pot A, this difference indicates the probability of the existence of different character inner strcture; however, more characters were covered by enamel. X-ray perspective images gave interesting results about the differences between pots (Fig. 2A-2, A-3, A-4, C-2, C-3, C-4). As with the comparison result of the metal matrix, the comparison of the structure of the four pots set pot A apart from the other three pots. The results are shown in Fig. 2. There were two main differences. First, it can be clearly seen in the X-ray photos that the handle of pot A was fixed on a predesigned protrusion of the pot body with screws (Fig. 2A-3), while in the other three pots (represented by pot C), the handles were directly welded onto the pot body. From a usage point of view, the fixation on pot A looks more durable. The second difference is found in the lids of the pots. As seen in Fig. 2A-4, the lid in pot A has a delicate design, leaving an exposed metal part on the top as decoration. Although it is not clear whether decoration was the only purpose of this design, it is a stunningly exquisite design. The lids in pot C, B and D were created using integrated casting, as shown in Fig. 2C-4. During the process of CT scanning the lid parts of Pot A, hidden information was discovered, and these results are discussed later in the article.

Glaze and pigments

The element analysis results for the glaze and pigments are shown in Table 2. It is clear that the glaze on pot A is a Pb-rich type glass (21% on average), with a small amount of K and Ca (1.5% and 0.8%, on average). In contrast, the glazes on the other three pots are potash-lead glass, with contents of Pb and K of approximately 30% and 10%, respectively (with less than 1% Ca).

To determine the coloring agents in the enamels, Raman spectra were used to detect the crystal phase in the glaze that presented the color. The results are shown in Fig. 3. Pots B, C, and D share almost the same Raman results, so the result for Pot B is chosen as the representative for all three pots in Fig. 3B, while the Raman result

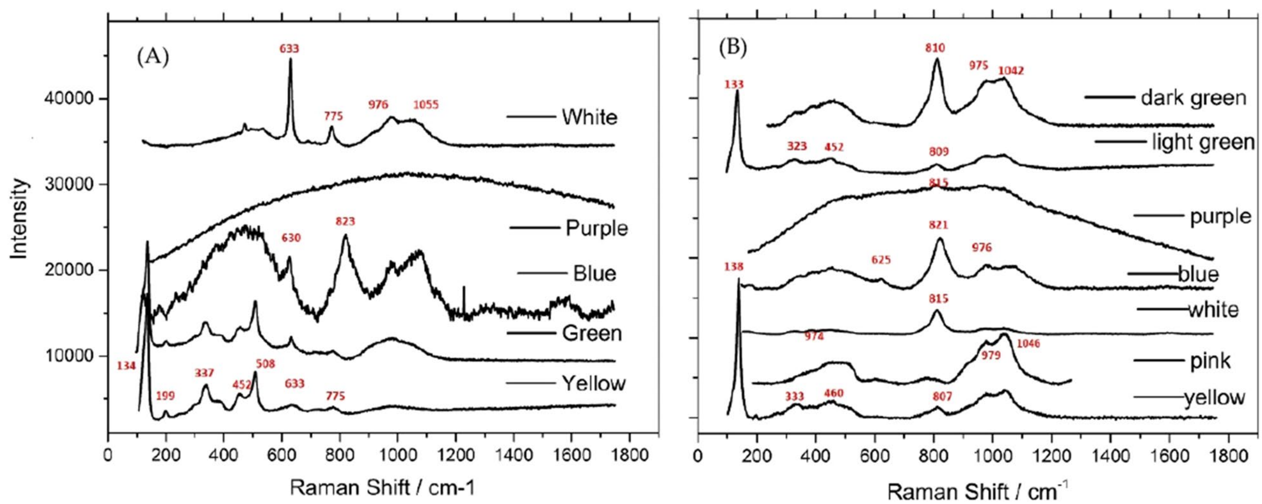

Fig. 3 The result for Pot B is chosen as the representative in **B**, while the Raman result for pot A is shown in **A**

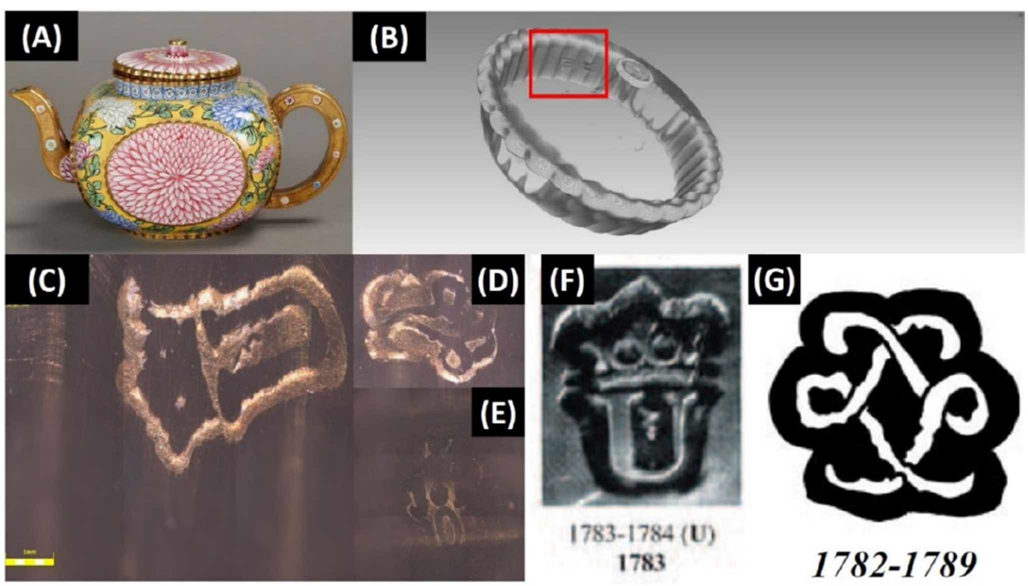

Fig. 4 **A** The pot in which the hallmark was found. This pot was most likely made in Paris, France. **B** X-CT image shows the hallmark located in the lid inner edge. **C**, **D** and **E** The three hallmarks found in that area. The meaning of these hallmarks has been clearly recorded in the archives of the Paris Goldsmiths Guild (**F**) and (**G**) show corresponding images found in the reference

for pot A is shown in Fig. 3A. In the table, the italic number emphasized the coloring agents in each enamels.

The greatest differences that could be found between pot A and the other three were in the white and yellow pigments. It can be seen from the Raman spectrum results (Fig. 3) that the white color on pot A was obtained from the opacification effect of tin dioxide (SnO_2) crystals in the glass, with symbolic peaks of 633 cm^{-1} and 775 cm^{-1}, and that the white color on pots B, C and D was obtained by the opacification effect of lead arsenate crystals, which could be confirmed by the presence of a peak between 810–821 cm^{-1}. Chinese and foreign painted enamels obviously privilege the use of these two kinds of white pigments. Until now, in Chinese painted enamels, only lead arsenate was found to produce the color white, while European craftsmen preferred to use tin dioxide to create white color in painted enamels. For example, according to a publication, the use of cassiterite opacification was typical of Coteau's work [32], but the conclusion is not that firm because some rare objects made in China (but under Jesuit guidance) were opacified with SnO_2 [14, 20]. Chinese craftsmen have used lead arsenate to paint white color on cloisonné since the late Ming and early Qing Dynasties in the seventeenth century [15, 16]. In terms of European white pigment technology, the opacification of cassiterite glass predates the Islamic period; it was used under the Roman Empire early in the fifth century and even earlier before that in the Celtic world, from the second to the first centuries B.C. [33, 34]. Compared with the common application of white tin in painted enamel and ceramic ware, arsenate-white arsenic was used later in Europe and was mainly applied to glass products. From the 17th to nineteenth centuries, Venetian and Murano glass craftsmen used arsenic white crystals to make opaque glass [18]. It seems that the use of arsenic white in painted enamel was not found in Limoges until the nineteenth century [3, 30].

The Raman results (Fig. 3) show that the yellow pigment used in pot A is Pb–Sn-Sb yellow, which is characterized by the elements lead, tin and antimony. It can be seen from the Raman spectra in Fig. 3A that peak 134 cm-1 corresponds to the Pb–O lattice mode, and the 508 cm-1 peaks were characteristic of Sb-rich Naples yellow. The yellow pigments used in pots B, C and D were lead tin yellow. This result is also consistent with elemental analysis, and the Raman results of strong peaks at 333 cm-1 and 450 cm-1 also provided evidence of Sn-rich compositions. The two kinds of yellow pigments show obvious differences in color, as yellow containing antimony appears more orange. Yellow pigment rich in antimony was not introduced from abroad until the Kangxi period in the late seventeenth century [19]. However, before the sixteenth century and after the seventeenth century, the most commonly used yellow pigment in enamel was lead tin yellow, both in Chinese cloisonné and painted enamels.

The dark blue in the four pots is colored by cobalt ions, but it is worth noting that the dark blue in pot A contains a trace of arsenic. Based on the belief that arsenic white was not used, the arsenic here most likely comes from the cobalt material itself, which produces the blue color; the character of the existence of arsenic in cobalt raw material is very consistent with the characteristics of European cobalt ores [20]. Regarding pots B, C, and D, Table 2 shows that the As content in the blue enamels is always higher than those in all the other colors, except, of course, for the arsenic-opacified white. This means that an As-bearing chromophore may have been used for the blue color. At the same time, the Mn content seems to always be below the detection limit of the XRF equipment; both of these characteristics are compatible with the chemical composition of European smalt and completely inconsistent with the chemical composition of Asian cobalt ores sourced locally [27, 28].

The composition of the pink pigments used in the four pots is not clear and is unsupported by the data due to the detection limit of the XRF equipment used for the study. However, in pot A, the pink must be made from gold because elemental analysis shows that pot A contains 0.2% gold, and the gold content in the pink on the other three pots is so low that it is below the minimum detection limit of the equipment. To directly provide evidence of the existence of pink golden red in pots B, C and D, electron microscope observations need to be carried out in further research.

The purple colors are different across the four pots. The purple on pot A is formed by the color combination of golden red and manganese ions, where the gold content is 0.1% and the manganese content is 0.2%; the purple on pot B and pot D is made of cobalt blue and golden red; the cobalt content in pot B is 1.1%, and the cobalt content in pot D is 0.3%. Although gold is still not directly detected, it is speculated that the red is most likely golden red. The purple on pot C is colored by manganese and cobalt ions, with a manganese content of 3.1% and a cobalt content of 0.3%.

The green colors originate from the mixture of yellow and blue colors. Combining the results of Raman and XRF results, it could be observed that the yellow pigments used in the green color were consistent with the yellow used in each pot. All the blue pigments in green pigment in the four pots were Cu-ion blue.

The light blue color could only be found in pots B and D on the part of the neck below the lid. It is interesting that the light blue color was different from the dark blue color on the same pots. The light blue color originated from Cu ions, while the dark blue color was made from Co ions. The light blue color produced by Cu ions also rely on the glass environment, the color of the glass can vary from green to blue with same amount of Cu ions in different glaze recipes. According to XRF analysis result the glaze of light blue enamel is potash-lead glass, the copper ions in this kind of glass usually show intense spectral transmission peak at 450 nm, which produce blue color in this kind of glass.

All the above analysis results for the four pots indicate that pot A is quite different from the other three in terms of metal, structure, glaze and pigments. From this information, it can be inferred that it likely that pot A was not produced in China, as the materials and craftsmanship are more similar to those found in Europe. This deduction was confirmed by hidden information found in pot A.

Hidden hallmarks provide chronological information

Three shallow hallmarks were found on the inner side of the lid in pot A. These were enlarged by the microscope, as shown in Fig. 4 C, D and E. These three hallmarks appear to be the stamps that the Paris Goldsmiths' Guild printed on French gold products. Compared with other countries, France has a set of quite complex systems for its gold and silver products, and there are roughly three types of product verification hallmarks: the craftsman's hallmark, tax declaration hallmark and purity hallmark [21]. These marks can be used to verify product information such as manufacturer, and place and year of manufacture. Figure 4E should be the craftsman's seal, usually composed of two or three capital letters: the two-letter seal is arranged on the left and the right; the left represents the first name abbreviated, and the right represents the last name abbreviated. If there are three letters, those on the left and right are initials, and the initials for last names are placed at the bottom in an inverted triangle arrangement. There are many crown symbols at the top of the logo, and lilies or other symbols are aligned with the middle point of the letter arrangement. The craftsman in the figure appears to be represented by "J · D · O". At present, no corresponding craftsman has been found; Fig. 4D appears to be the tax hallmark. According to the relevant laws regulating the trademark and the guild, a goldsmith sends the semifinished products with the craftsman hallmark for declaration to the tax unit, where the tax collector prints the tax stamp. The design of this tax hallmark varies from region to region. For example, in Paris, the main body of the tax hallmark for large gold and silver products features the crown with letters, and different letters correspond to different time periods. A comparison of different historical documents [22] reveals that the hallmark found in pot A corresponds with the hallmark in Fig. 4G, so that it can be said that pot A must have been produced between 1782 and 1789. Figure 4C features the purity hallmark. In Paris, once tax stamped, semifinished products must be sent to the goldsmith guild to verify whether the purity meets the guild's specifications. After verification, the purity hallmark is printed. The purity hallmark adopted by the Paris Goldsmiths' guild is coded in alphabetical order, with one letter being changed each year. Modest provincial guilds can modify an alphabet stamp only every two to ten years. The hallmarks shown in Fig. 4C are a close match to Fig. 4F, indicating that the pot must have been produced in 1783 [22]. This finding is consistent with the information provided by the tax hallmark. In conclusion, pot A is a pot produced in Paris, France in 1783 (the 48th year of the Qianlong Emperor).

Discussion

Through scientific analysis and interpretation of hidden hallmarks found in the pot, the origin of pot A can be decidedly attributed to Paris, France. How did such an artifact that was made in a foreign country arrive at the Chinese court? According to the archival research, pot A was a commercial order placed by the emperor Qianlong with French craftsmen rather than a routine diplomatic gift.

The most habitual channel for foreign artifacts to enter the court was as diplomatic presents. In the Qing dynasty in China (seventeenth-nineteenth century), a large number of foreign artifacts, including painted enamels, were presented to the Chinese Emperor as gifts through diplomatic actions. For example, in 1687, French king Louis XIV dispatched a 6-member mission headed by J. de Fontaney (1643–1710, Chinese name: Hong Ruo), who brought a selection of enameled wares (clocks and watches) from France as a gift to the Chinese court [23]. One month after Hong Ruo arrived in Ningbo, he wrote to France and reported, "Painted enamels are very popular and hope to send more".

The origin of pot A can be found in the royal archives regarding the artifacts made for and presented to the Emperor（清宫《造办处活计档》). In 1775 (40 years into the Qianlong reign), the Qianlong Emperor ordered Guangdong Customs to imitate a batch of brand-new painted enamels based on the enamels he already had. Pot A figures among these artifacts. It is worth noting that, in Emperor Qianlong's order, it is specifically stated that in making these artifacts, craftsmen should use foreign enamel techniques rather than local skills [24]. His minister might have misunderstood his intention and just made a commercial order from France instead. This special request from the emperor explains the existence of this French enameled pot at the Chinese Court. Moreover, additional evidence was found to prove that some painted enamel pieces collected by the Palace Museum were made abroad and came into the Court through commercial orders rather than through the diplomatic channel. For example, Chuping Wang found some hallmarks in an enameled bowl with a golden body that indicated that the bowl was made in Paris, France in 1777 [25].

To date, one question remains: why and where were the other three pots produced? Combining the results of the scientific and archival analyses, it can be concluded that these three pots (BCD) were most likely to be made in Guangdong Province, China after 1775. During the Qing Dynasty in China, painted enamels were first produced in a special workshop in the royal palace (which is the Palace Museum today) by Emperor Kangxi at the end of the seventeenth century. In fact, the emperor was so fascinated by the painted enamel that this workshop was located just beside his bedroom and kept producing painted enamels for the royal family until 1758, when some manufacturing jobs were assigned to the new craft center, Guangzhou. The archives showed that this move was due to Emperor Qianlong's financial problems at that time [26].

The archives also revealed that in 1775 (40 years into the Qianlong reign), Qianlong Emperor ordered Guangdong Customs to copy a batch of brand-new painted enamels based on enamels he already had. This order included 10 artifacts, and the pot investigated in this study was included. This order was not a one-off order; it lasted for a long time. This means that the Guangzhou workshop repeatedly imitated the pot and other artifacts. Records at least show that in 1777 and 1784, the royal palace in Beijing noted the receipt of this order, and based on the existence of the three pots, it can be speculated that other pots exist that were not recorded in the archives. Among the collection of painted enamels in the National Palace Museum in Taiwan Province, China, there is another pot that is quite similar to pots B, C and D here. To date, it can be concluded from this royal order that at least 4 pot copies were produced in China and one copy was produced in Paris, France. These copies did not constitute a waste of time and money, as they feature in the painted enamel manufacturing history in China. After Emperor Kangxi successfully initiated the production of painted enamel, his son (Emperor Yongzheng) and grandson (Emperor Qianlong) inherited his aesthetic idea and developed painted enamels with Chinese character. However, both of them kept the tradition to imitate the painted enamels made in the Kangxi period to show respect toward their father and grandfather.

Conclusions

In this paper, scientific detection and analysis were performed on four similar enameled pots collected in the Palace Museum, and a number of aspects of the characteristics of these pots were compared, such as metal material, process structure, enamel glaze, and pigments. Based on these comparisons, pot A was obviously different from the other three pots. The metal in pot A is almost pure gold, while the other pots are made of copper gilded with gold. The glaze used in pot A is rich in Pb, while the other three pots are covered in glaze rich in Pb and K. The difference in pigments used in these enameled pots also shows the preferences of different workshops and craftsmen. The white color in pots B, C and D is created by arsenic white, and the yellow is lead–tin yellow. The corresponding white in pot A is tin white, while the yellow is lead–tin-antimony yellow. These results indicate that it is very likely that pot A was produced in Europe, while the other three pots were produced locally in China. This conclusion was proven by the hallmarks found in pot A, indicating that pot A was produced in Paris, France in 1783 to fulfill a commercial order made by Emperor Qianlong's minister.

From the perspective of scientific analysis, these results provide new evidence regarding the history of enamel exchange between Chinese and foreign countries. The study proves that some of the painted enamel pieces collected by the Palace Museum were made abroad and came into the court through commercial orders rather than as diplomatic gifts. Further research on painted enamel samples is encouraged to find additional characteristics that can be used to distinguish painted enamels that were produced in different countries and ages.

Appendix A

See Table 2

Table 2 Element Detection Results for the Glaze in the Four Pots(%wt)

		Au	SiO2	K2O	CaO	MnO	Fe2O3	CoO	CuO	ZnO	As2O3	ZrO2	SnO2	Sb2O3	PbO
Pot A	White	0.00	57.25	1.17	1.13	0.00	0.15	0.00	0.02	0.00	0.17	0.04	*20.29*	0.00	19.78
	Green	0.00	47.83	0.95	0.80	0.02	1.47	0.02	*2.42*	0.00	0.34	0.05	*17.98*	0.09	*28.00*
	Blue	0.00	62.40	3.54	0.59	0.01	0.31	*2.57*	0.02	0.00	0.44	0.02	10.19	0.00	11.98
	Purple	*0.21*	55.19	1.39	1.01	0.01	0.22	0.02	0.02	0.00	0.22	0.04	20.20	0.00	21.47
	Pink	*0.08*	70.09	4.32	3.41	0.16	0.42	0.00	0.03	0.01	0.12	0.02	9.78	0.00	11.25
	Yellow	0.00	50.14	0.93	0.00	0.04	1.74	0.01	0.03	0.01	0.26	0.05	*20.18*	0.48	*24.71*
Pot B	White	0.00	47.4	11.0	0.8	0.0	0.1	0.0	0.5	0.2	*4.8*	0.1	0.0	0.00	35.1
	Pink	0.00	46.4	9.4	0.2	0.0	0.1	0.0	0.1	0.2	1.7	0.1	0.0	0.00	41.7
	Yellow	0.00	57.8	7.3	0.3	0.0	0.1	0.0	0.0	0.2	0.3	0.1	*1.6*	0.00	*32.3*
	Light Blue	0.00	60.2	13.7	2.6	0.0	0.2	0.0	*1.7*	0.1	2.9	0.0	0.0	0.00	18.6
	Green	0.00	58.2	8.5	0.3	0.0	0.2	0.0	*1.0*	0.2	2.3	0.0	0.1	0.00	*29.2*
	Blue	0.00	60.3	15.9	1.2	0.0	1.2	*1.1*	0.1	0.0	3.9	0.0	0.0	0.00	16.1
	Purple	0.00	58.9	9.6	0.4	0.0	0.3	0.2	0.0	0.2	2.1	0.0	0.0	0.00	28.3
Pot C	Pink	0.00	44.0	8.5	0.4	0.0	0.1	0.0	0.1	0.0	1.4	0.1	0.1	0.00	45.3
	White	0.00	52.1	5.5	1.3	0.0	0.1	0.0	0.0	0.2	*3.3*	0.1	0.0	0.00	37.4
	Yellow	0.00	41.4	8.0	0.3	0.0	0.1	0.0	0.0	0.3	0.4	0.1	*1.4*	0.00	*48.0*
	Green	0.00	62.0	5.8	0.0	0.1	0.4	0.0	*2.6*	0.0	0.6	0.0	*0.6*	0.00	*27.8*
	Blue	0.00	56.2	11.8	0.9	0.0	0.8	*0.6*	0.1	0.2	2.1	0.1	0.0	0.00	27.0
	Purple	0.00	53.5	8.9	0.7	*3.1*	0.7	0.3	0.1	0.1	1.9	0.1	0.0	0.00	30.6
Pot D	White	0.00	45.2	10.6	0.6	0.0	0.0	0.0	0.1	0.2	*5.4*	0.1	0.1	0.00	37.8
	Pink	0.00	47.2	8.8	0.3	0.0	0.1	0.0	0.0	0.2	1.5	0.1	0.0	0.00	41.8
	Yellow	0.00	37.2	8.7	0.3	0.0	0.2	0.0	0.0	0.3	1.1	0.1	*1.5*	0.00	*50.6*
	Light Blue	0.00	58.7	13.3	2.7	0.0	0.2	0.0	*1.6*	0.1	3.0	0.0	0.2	0.00	20.3
	Blue	0.00	54.4	17.9	1.4	0.0	1.3	*1.2*	0.1	0.0	4.3	0.0	0.0	0.00	19.3
	Green	0.00	44.8	7.5	0.3	0.0	0.2	0.0	*1.8*	0.2	0.8	0.1	*0.8*	0.00	*43.5*
	Purple	0.00	47.9	10.7	0.5	0.0	0.4	*0.3*	0.0	0.2	1.9	0.1	0.0	0.00	37.8

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Author contributions

"Project leader and mainly writing, HL; CT scanning, HG; Element XRF analysis, PD; HW, RZ; resources and archive information; writing—review funding acquisition and supervision, LQ. All authors read and approved the final manuscript.

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Data availability

In this work, the original data are shown in Appendix A, and any other further data are available upon request from the authors.

Declarations

Competing interests

The authors declare that they have no conflicts of interest in this work. We declare that we do not have any commercial or associative interest that represents a competing interest in connection with the work submitted.

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