



HAL
open science

Using Noninvasive On-site Analysis to Decipher, Understand, and Compare the Enameling Techniques of Imperial Enameled Artefacts of the Qing Dynasty

Philippe Colomban

► To cite this version:

Philippe Colomban. Using Noninvasive On-site Analysis to Decipher, Understand, and Compare the Enameling Techniques of Imperial Enameled Artefacts of the Qing Dynasty. Blythe McCarthy, Jennifer Giaccai, Matthew Clarke and Kesha Talbert. Technical Studies of Asian Art. Proceedings of the Seventh Forbes Symposium at the Freer Gallery of Art, Archetype Publications Ltd, pp.175-181, 2026, 9781916642089. <hal-05560168>

HAL Id: hal-05560168

<https://hal.science/hal-05560168v1>

Submitted on 20 Mar 2026

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Copyright - All rights reserved

TECHNICAL STUDIES OF ASIAN ART
Proceedings of the Seventh Forbes Symposium at the Freer Gallery of Art

Edited by Blythe McCarthy, Jennifer Giaccai, Matthew Clarke and Kesha Talbert

First published 2025 by Archetype Publications Ltd, Archetype Publications Ltd,
128 City Road London EC1V 2NX
www.archetype.co.uk © 2025 Smithsonian Institution, Washington, D.C

**Using Noninvasive On-site Analysis to Decipher, Understand, and Compare
the Enameling Techniques of Imperial Enamelled Artefacts
of the Qing Dynasty**

Philippe Colomban

Laboratoire 'De la Molécule au Nano-objet : Réactivité, Interaction et Spectroscopies,
(MONARIS UMR8233), Sorbonne Université, CNRS, Campus P.-et-M. Curie, 4 Place Jussieu, 75005
Paris, France ; philippe.colomban@sorbonne-universite.fr ORCID : 0000-0001-6099-5423

Abstract

Using mobile Raman and x-ray fluorescence (XRF) spectrometers, measurements taken from artifacts in the Asian and European collections of different European museums allowed the identification and comparison of the phases – crystalline and amorphous – and of the chemical elements constituting the blue, yellow, green, red-to-pink, and violet enamels of porcelains and metalwares attributed to either the imperial workshops of Beijing or Jindezhen or the customs district of Canton (Guangzhou).

After the importation of European recipes and ingredients at the end of Kangxi's reign, a "return" to traditional Chinese techniques is observed for Yongzheng productions. In particular, comparison of the (normalized) signals of the elements associated with the blue chromophore element (Co, Mn, As, Ni, and Bi) and those associated with the ingredients of the silicate matrix of the enamel (Sr, Rb, Y, and Zr) distinguish productions made in Canton from those made in Beijing under the Qing emperors, as well as earlier Ming productions. Discovery of "pure" cobalt (which requires a purification process available only from the second half of the nineteenth century) attested to a later production, incompatible with the reign mark inscribed on the object examined.

Objective

Studies of Chinese and European archives and correspondence (Bellemare 2022; Curtis 2019; Shih 2007, 2021, 2022; Xu 2015; Wang 2022) have noted the attention paid by the Qing emperors to enameled objects offered by European emissaries and missionaries, the importation of ingredients, and the arrival in China of French and Italian experts in painting and in the production of glass and enamels at the turn of the seventeenth and into the eighteenth centuries. These experts established “imperial” workshops (from 1693) in the Tartar city of Beijing, adjoining the Forbidden City. Also, private ones (probably earlier) that produced goods for the Chinese and European markets were established at Canton in relation with East Indian Companies. Analysis of Arita porcelains (Kan'ei period) and rare archives show that Portuguese Jesuits had taught European painting techniques on different substrates one century before then (Montanari et al. 2018, 2020).

Since material composition can provide much evidence on the production process of an object, the objective of this paper is to report the analytical procedures that enable documentation of the manufacturing technique of enameled objects (porcelain or metal) of the Qing dynasty. These procedures are carried out in a perfectly noninvasive way using mobile instruments in the objects' places of conservation in order to identify the use of ingredients and/or recipes imported from Europe and the pieces produced therewith. This approach is based on the author's long experience in the study of ceramics, glass, and enamels with sophisticated decoration, such as European, Islamic, and Asian porcelain and glass, Limoges enamels, cloisonné enamels, and so on (Colomban 2020).

Constraints Imposed in the Study of Rare (Enameled) Objects

The fragile nature and high value of certain cultural heritage objects imposes specific constraints on their study and in particular their analysis. Such limitations may include being unable to take samples of the material or move objects from their places of conservation, to avoid the costs of transport and insurance. Observation and analysis can be done only on or via the surface, without contact, therefore without detailed information on the stratigraphy of the material. The analysis techniques must therefore be based on the use of radiation which, by its interaction with the material, reveals information about the object's nature, structure, composition, corrosion, and so on. These constraints affect the information collected. Any analysis must take into account the heterogeneous nature of these sophisticated painted enamels, with scale ranges across a few nanometers to several centimeters of material. The objects studied are rare artifacts, the jewels of collections, and therefore the time available for their study is brief.

On-site Noninvasive Analytical Tools and Procedures: Glass Matrices and Colors

A glaze is a layer of glass (an amorphous silicate) formed on a substrate. Color is obtained by the incorporation of one or more coloring agents in the glassy matrix: ions absorb certain parts of the visible spectrum, as metallic or semiconducting nanoparticles or grains of pigment colored by the above ions. Laboratory experience indicates that the best way to analyze a glaze is the combination of two mobile methods, portable x-ray fluorescence spectroscopy (pXRF) (Colomban, Gironde, et al. 2021) and Raman microspectroscopy (μ Raman), an inelastic scattering of monochromatic coherent light (laser) (Edwards et al. 2023). Figure 1 shows the mobile devices being used in museum. The pXRF interacts with the deep electronic layers of the atoms and provides information about the nature of the chemical elements present in the surface irradiated by the instrument (the “elemental composition,” although elements lighter than potassium are not measurable). The μ Raman interacts with the external electronic layers forming the chemical bonds and provides information on its composition (e.g., sodium, potassium, lead, or boron glass), the (nano)structure of the crystalline (pigments) or amorphous phases (silicate matrix), and their symmetry. The surface area analyzed by pXRF varies depending on the instruments ($\sim 1 \text{ mm}^2$ in this case); in μ Raman with a choice of illumination and signal-collection optics,

the surface area varies between ~ 1 and $500 \mu\text{m}^2$. Both techniques allow mapping by displacement of the analysis area.



Figure 1. (a) Mobile Raman analysis device. (b) The laser spot halo for Raman analysis. (c) Mobile XRF analysis device. The motorized positioning of the XRF spectrometer on a stand is controlled to the nearest millimeter by a camera. (d) The coincidence of two laser spots is shown on the piloting laptop (yellow arrow in (b)); the positioning of the laser spot for Raman analysis is controlled by three manual micrometric screws on the stage shown in (a). Photo P. Colombari.

It is not easy to calculate how deeply the radiation has penetrated: it depends on the energy of the source, the process of illumination, and the material of the object. Thus, in pXRF, light elements (K, Ca, Al, Si) are measured in the very surface layer (a few μm), transition metals (the main coloring agents) over 200 to 300 microns (i.e., of the order of a layer of enamel), and heavy elements (Pb, Bi, Sn, Sb, etc.) in thicknesses up to the order of millimeters. The measurement is then strongly affected by the variation in thickness of the layers of enamel, and the nature of the substrate if the enamel is less than a few millimeters thick (Colombari, Gironda, et al. 2021; Colombari et al. 2023). Laser penetration for μRaman can be controlled over several tens or even hundreds of microns, depending on the transparency/coloration of the analyzed area.

Information Extracted from the Archives

For centuries, European archives were used to document the importation into Europe of Chinese and Japanese porcelain, and the search for information on Asian know-how concerning the production of ceramics (for example, the correspondence of Father D'Entrecolles). The correspondences of Jesuit and Franciscan missionaries and the imperial archives also document what China received from Europe. The missionary's correspondences report requests made by Chinese emperors from the 1680s for aid in producing in China objects similar to presents they had received and to set up workshops close to the Forbidden City. The missionaries asked their authorities to send ingredients, recipes, and expert technicians.

The Chinese archives note requests from the emperors to extend the range of colors and their appreciations of the first objects made, and so on. Pieces imported from Europe in the imperial collections are identified in the archives (order, initial place of conservation, etc.), as are pieces copying the models ordered in Europe. Passages in the archives suggest a change from a limited chromatic palette (*wucan*: 5 colors that cannot be mixed) to more than 30 mixable colors (Wang 2022). The archives also indicate the exchange of information and movements of craftsmen between the three main places of production: the official and private kilns of Jingdezhen for the production of porcelain and the creation of underglaze decorations, the workshops for the production of glass and enameling in Beijing (near the French Beitang church), and the workshops of the Canton customs for enameling.

Enamel Painting in the Seventeenth Century: Vitreous Matrices and Coloring Agents: Technical and Geological Context

In the sixteenth century, painting was the major European artistic technique: paintings reached very high values and works were based on the mastery of a wide range of colors. At this time, the decoration of ceramics (majolica from Urbino, Lyon, Faenza, etc.) began to be inspired by “fashionable” paintings, often scenes from Greek or Roman mythology or the Bible, or of famous people. Enamellers on metal, in particular in Limoges or those working for the court of France who settled in Blois, then in Paris, in the seventeenth century (Colomban et al. 2020), developed techniques that allowed a range and quality equal to that of pastel or oil paint (figs. 1 and 2). At that time, Chinese craftsmen had a very limited palette because their only coloring agent was created by the dissolution of transition-metal ions in the vitreous network. The decoration was either monochrome, made by coloring the cover or by laying under the cover a drawing in blue (the famous blue and white) or limited to a few flat colors such as in watercolor.



Figure 2. (a) French enamel decoration of a watch, ca. 1640 (inv. OA8428, Coll. Musée du Louvre, Paris). (b) For comparison of know-how in the same period, an enamel decoration of a Chinese doucai bowl dating from the second half of the seventeenth century to the beginning of the eighteenth century (inv. G5696, Coll. Musée national des Arts asiatiques-Guimet, Paris). (c) Famille verte porcelain shard (private coll.). (d) Famille rose porcelain shard (private coll.) Photo P. Colomban.

Lead-tin yellow pigment appeared during the reign of Wanli (1573–1620, at the end of the Ming dynasty) and seems to be the first pigment used, if we exclude opacification with fluorite (at least since the Liao period) and the use of copper nanoparticles (Jun ware, thirteenth century) (Zhang 1985; Kingery and Vandiver 1986). The use of European techniques gave rise, according to the classification of Albert Jacquemart in 1862, to famille verte (addition of green overglaze, colored by copper ions) and famille rose (use of nanoparticles of gold as in purple of Cassius), combined with blue-and-white underglaze decoration (see fig. 2) (Colomban, Ngo, et al. 2022). Although the incorporation of these European techniques widened the color palette, it remained impossible to achieve such sophisticated decorations as in oil painting (see fig. 2).

The Chinese potters used a firing process in a reducing atmosphere, which is essential for creating a white paste but also for the copper red (jun ware, blood of ox, blood of pigeon, sacrificial colors ware) (Zhang 1985), and for the blue and white. A very reductive firing process is required for the blue coloring, because the geological context of the raw material used to create it contains iron, manganese, and cobalt in comparable quantities (Colomban, Simsek Franci, et al. 2021). In contrast, European cobalt ores, from hydrothermal veins, are free of iron and manganese (Colomban, Simsek Franci, et al. 2021) so the artifact can be fired in an oxidizing atmosphere. European ores contain nickel, bismuth, silver, and arsenic. Until the eighteenth century, cobalt was a by-product of the extraction of silver and arsenic. In addition, the strong presence of arsenic magnifies the color by forming a white opacifier in a lead-based glassy matrix. European enamellers produced a wide range of colors fired in an oxidizing atmosphere (in a muffle or glass furnace) at temperatures between $\sim 650^{\circ}\text{C}$ and 1050°C with alkaline or lead-alkaline vitreous matrices but also using borax (Colomban, Ngo, et al. 2022).

Many pigments used since antiquity or developed during the Renaissance were prepared separately (*anima*) in frit form and incorporated into the silicate matrix (*corpo*), (Colomban 2020) and were available to potters and enamellers. Lead-tin and Naples yellows (addition of iron, zinc, and antimony) in an enamel colored by Co^{2+} (blue) or Cu^{2+} (green) ions give a wide variety of yellow and green tints (Colomban et al. 2020; Colomban, Simsek Franci, et al. 2021; Colomban, Gironda, et al. 2021). The incorporation of gold nanoparticles precipitated from gold dissolved in aqua regia by adding tin (Kunckel's method, or the so-called purple of Cassius) or arsenic (Perrot's method) colors the glass in hues ranging from ruby to violet (Colomban, Simsek Franci, et al. 2021; Colomban, Gironda, et al. 2021). Several pigments or opacifiers widely used in Europe were unknown in China until almost the end of Kangxi's reign. These were cassiterite, lead-calcium/potassium arsenates, Naples yellows, and gold nanoparticles. The highlighting of these crystalline phases will be proof of the use of European recipes. The presence of certain impurities and/or certain ratios characteristic of the geology of the raw materials may be a signature of their origin.

Finding European Pigments and Coloring Agents

The presence of chromophore ions dissolved in glaze can be identified by their color (by simple visual examination or by measuring its UV-visible absorption spectrum) and confirmed by pXRF. The detection of coloring crystalline phases based on European recipes is mainly obtained by μRaman ; this technique identifies the phases and further characterizes their structure and crystallinity. Illumination by a laser can also trigger another optical phenomenon, fluorescence (or more precisely luminescence), which is sometimes much more intense than the Raman signal. This is the case if the glass contains metallic nanoparticles, which in themselves are not detectable by Raman spectroscopy with mobile instrumentation (Edwards et al. 2023).

Figure 3 shows a selection of Raman and XRF spectra representative of the different observable signatures for enamels of different colors. The spectrum of a golden bowl from the reign of Kangxi shows only a background of fluorescence modulated by the response of the instrument (Colomban, Simsek Franci, et al. 2022). For white enamel, a peak at $\sim 820\text{ cm}^{-1}$ indicates opacification by an arsenate of lead and calcium/potassium (Colomban, Zhang, et al. 2017; Colomban, Ambrosi, et al. 2017). The blue of the mark (underglaze) shows a peak at $\sim 460\text{ cm}^{-1}$ characteristic of the presence of quartz grains, and a spectral bump around 510 cm^{-1} is characteristic of a glassy aluminosilicate, this double signature being that of a cover of porcelain. The blue area shows an intense peak of arsenate, which is consistent with the use of cobalt imported from Europe (Colomban, Simsek Franci, et al. 2021). The spectrum recorded on the green leaves is that of lead-tin yellow, while that of the orange heart of the flowers is characteristic of a Naples yellow with a pyrochlore structure based on lead and antimony (Colomban, Zhang, et al. 2017; Colomban, Ambrosi et al. 2017; Colomban, Ngo, et al. 2022; Colomban et al. 2023). The wide bands around 1000 cm^{-1} are those of the silicate matrix (*corpo*). The black lines here are based on manganese and iron oxides.

The pXRF spectra shown on the right-hand side of figure 3 make it possible to identify the elements present in the bowl's enameling: the glaze is free of lead and is based on silicon, potassium, and calcium. Note that the intensities are not proportional to the contents and a calculation must be made (Colomban, Ngo, et al. 2022; Colomban et al. 2023).

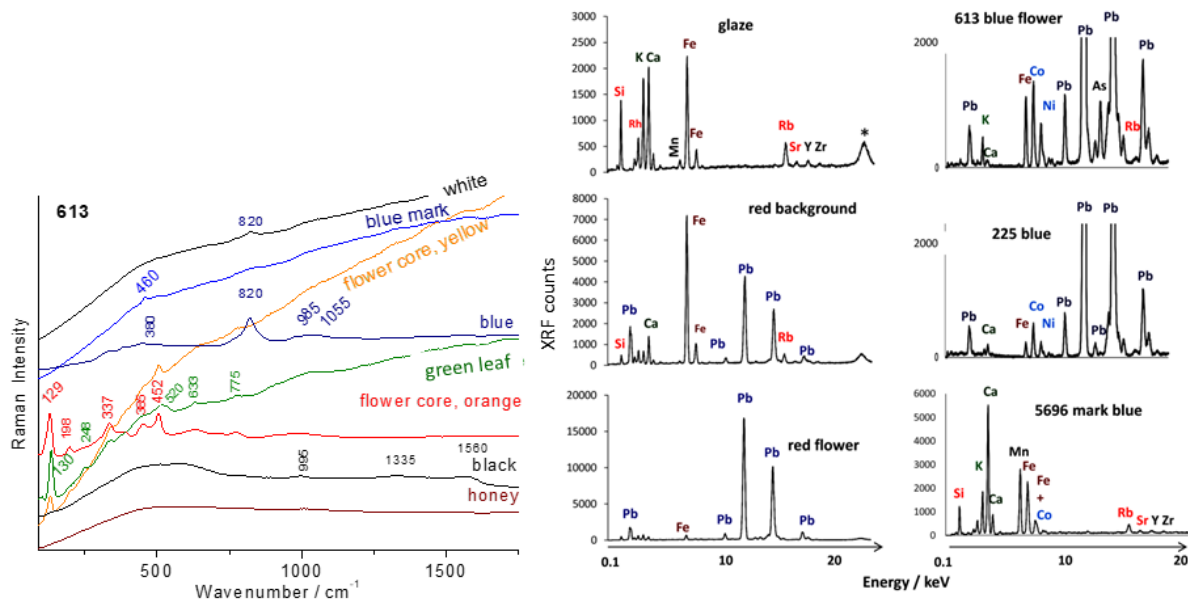


Figure 3. Examples of Raman (left) and pXRF (right) spectra recorded on stained areas of Qing porcelain (huafalang bowl, inv. CC.CB.1932.613 (simplified label: 613), Kangxi mark, Coll. Musée d'Extrême-Orient, Baur Foundation, Geneva; doucai bowl, inv. G5696 (simplified label 5696), Kangxi mark, see Figure 2; comparison with a Meissen (Saxony) plate, inv. AR-2001-225 (simplified label 225), Musée de l'Ariana, Geneva). The colors of the enamels and the inventory numbers are indicated. For detailed information regarding the objects, see Colombari, Simsek Franci et al. 2022.

On the other hand, the peaks of some traces (here, rubidium, strontium, yttrium, and zirconium), in quantities 200 to more than 1000 times lower than silicon, the main element, are very visible. It is evident that the source of cobalt used for the mark of bowl 5696 (see fig. 3) is very rich in manganese (mark affixed under glaze at Jingdezhen) and is therefore based on “Chinese” cobalt (Colombari, Simsek Franci, et al. 2021), while the blue flower is a lead enamel colored by a European cobalt (associated with nickel and arsenic, i.e., the smalt provided by Dutch merchants), a little different from the blue of another object of the same collection.

For any object, the μ Raman and pXRF spectra recorded on different colored areas make it possible to identify the cases where chemical elements or phases typical of European technologies are present. The most relevant cases are the opacifier cassiterite, Naples yellow based on antimony and zinc, dark blues associated with arsenic, and pinks associated with gold associated to arsenic or tin.

Identification of Production Sites

The pXRF data are corrected with software to make it possible to visualize the spectra and, if the analyzed volume is homogeneous and infinite, to calculate the composition of elements heavier than sodium. However, in the case of painted enamels, the material is not homogeneous enough for a calculation to be accurate. Therefore, the intensities of the characteristic signals of the different elements have been compared (i.e., the peak areas after corrections related to the variable measurement conditions); these are shown in ternary diagrams, as in figure 4.

First under consideration are trace elements that present a fairly intense peak in pXRF, characteristic of the geology of the raw materials used to produce the glass layer: yttrium (impurity of feldspars and quartz), rubidium, and strontium (respective impurities of the alkalis (Na, K) and alkaline earths (Ca)). The comparison of measurements made on French soft porcelain from the end of the seventeenth and the beginning of the eighteenth centuries and Chinese porcelain from the Yuan and Ming periods (Colombari et al. 2023) shows disjointed localizations, at the top right for the French, and at the bottom left for the Chinese, because the geological contexts of Chinese and French raw materials are very different.

For the Ming period, Vietnamese porcelains are also represented; their geology is rather close to the Chinese and the two sets of data are associated but distinguishable. For data relating to the enamels of Qing objects according to the glazed areas of the pieces, three categories are identified: i) location as for Ming (and Yuan) porcelains; this is the case for glazes; ii) location with data from French porcelains and iii) between these two groups, distributed on a line parallel to the Y-Rb side. This is observed both for blue enamels and for other colors. The distribution on one line proves the mixed use of European and Chinese raw materials (Colomban et al. 2023).

The same approach can be taken for the diagrams concerning cobalt and the associated elements characteristic of different geological contexts: arsenic/nickel/bismuth typical of European mines and manganese from Chinese mines (fig. 4). Note that the blue of the marks (affixed to Jingdezhen) lies mainly on the Co-Mn line, while the decoration is close to the As apex because it has been made with European cobalt. Normalization of the data with respect to the cobalt signal increases the sensitivity: we see in figure 4 that all the Ming and Yuan porcelains are on the Mn-Fe line, whereas the data of the Qing porcelains are distributed toward the nickel vertex. This process is also carried out for the associations of gold and arsenic and gold and tin to discover whether the gold nanoparticles of the pink-to-violet colors are obtained with arsenic by the method of Perrot or with tin by that of Kunckel. Here, the association with arsenic is mainly observed (Colomban et al. 2023).

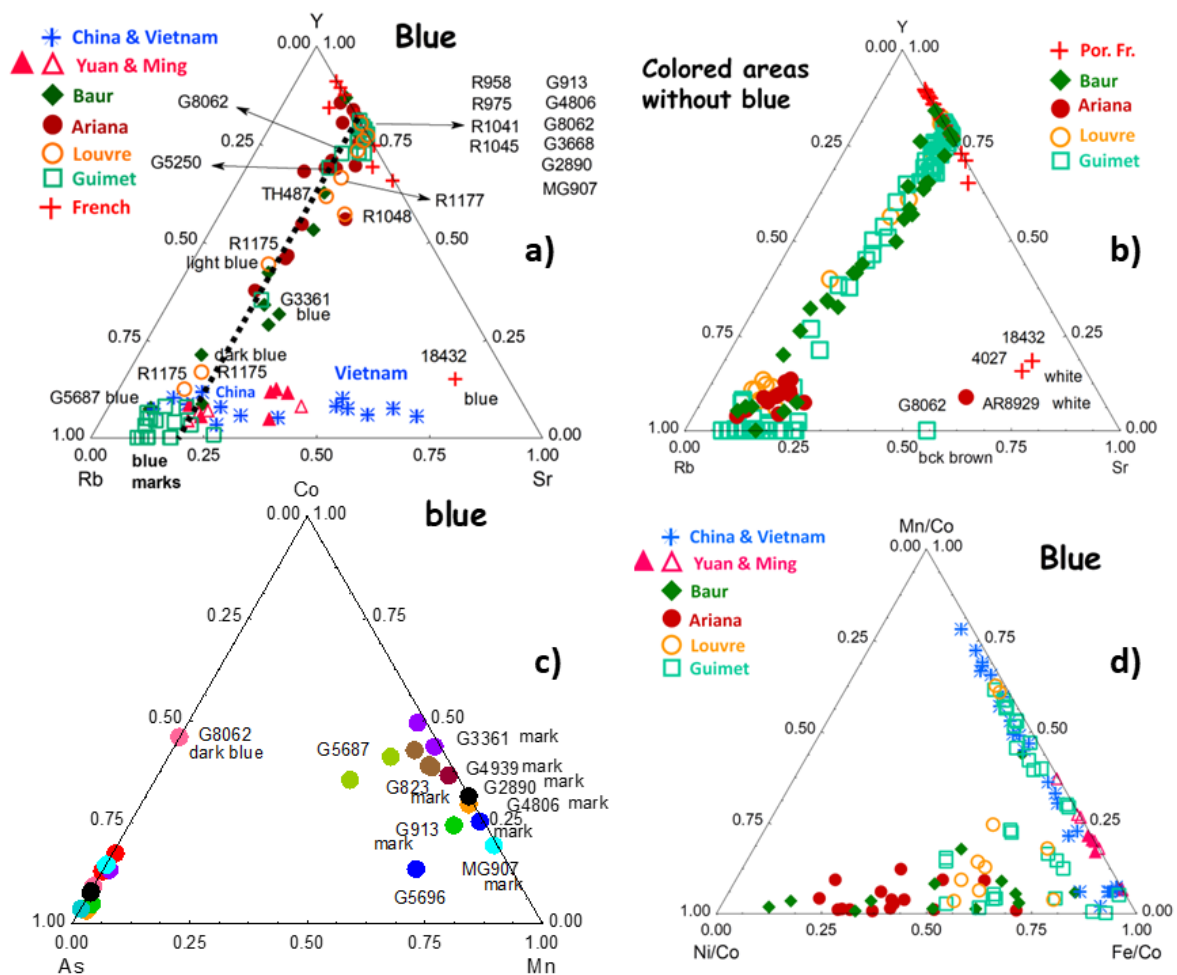


Figure 4. The XRF signals of Y, Rb, and Sr elements characteristic of the glassy matrix (a,b) and of Co, As, Mn, Ni, Fe elements (c,d) associated with the blue-colored areas (for artifacts from different origins (Yuan and Ming: archaeological shards from sites in Vietnam and China from the Yuan and Ming dynasties; Por. Fr.: French eighteenth-century porcelain; Qing artefacts (Musée du Louvre, MNAAGuimet, Baur Foundation, and Ariana Museum Collections). In (c), all items from the Musée national des Arts asiatiques-Guimet collection, Paris. A comparison is made with other colored areas.

See Colomban, Simsek Franci et al., 2022, Colomban, Simsek Franci, Gironda et al. 2022, and Colomban et al., 2023 for more information.

Why European Recipes and Pigments?

The double evidence from the archives and the pXRF and μ Raman analyses supporting the use of European recipes and/or ingredients for the preparation of overglaze colors blue, white, yellow, green, and pink-to-purple leads to several questions. Why resort to these imports of products and techniques? How were these practices incorporated and local substitute materials used? Are there differences according to the reigns? Are there differences between the practices in Canton, Beijing, and Jingdezhen, in particular according to the productions for the emperor, for the Chinese market, and for export? This current work provides some answers.

The need to use imported cobalt is explained by the firing in an oxidizing atmosphere that is required for complex realistic decoration. Indeed, the archives indicate the use of glass furnaces, classic for the enameling of glass and metal objects and for simplicity of the oxidizing process. The cobalt traditionally used in China contains too much iron and manganese to obtain blue by oxidizing firing. For green and yellow colors, the mixed-composition pyrochlore pigment Pb-Sn-Sb-Zn (Fe) is arguably more tolerant of differences in firing temperatures than the monochrome Ming iron yellow. Before the arrival of the Manchu dynasty, the polychromy of ceramic decorations was limited in accordance with traditional Chinese aesthetics.

Cassiterite opacification is found in a few pieces, imperial, but lead arsenate opacification (several phases identified) is the most common technique. Local sources of arsenic had to quickly replace imported ingredients. In Europe, opacification with arsenic is a technique of Venetian glassmakers and before the middle of the nineteenth century was used in ceramic enamels only to adjust the tones of blue.

From the corpus studied it is evident that although European recipes were widely used during the end of the reign of Kangxi and that of Qianlong, under Yongzheng there was somewhat a return to Chinese technical solutions. Regarding the blue enamels studied in detail, there are differences between products of the imperial workshops and those of Canton for export; the mixture of European and Chinese cobalt appears to be common in Canton.

The analyses performed were focused on a small number of imperial artifacts, a few dozen in all, and the representativeness of the results can perhaps be questioned. Shih (2022) indicates that 400 imperial porcelains and 200 metalware objects are kept in the collection of the Palace Museum in Taipei. Export specimens are much more numerous. The use of noninvasive mobile instruments must allow a true statistical approach.

Acknowledgments

The author acknowledges coworkers and the staff and head of the Musée du Louvre, Château de Fontainebleau, Cité de la Céramique-Sèvres and MNAA-Guimet in France and Fondation Baur and Musée de l'Ariana in Switzerland, as well as collectors for the permission to analyse artifacts. Partial support from Agence Nationale de la Recherche ANR EnamelFC project—19-CE27-0019-02.

References

- BELLEMARE, Julie. 2022. A new palette: Reassessing the development of enamel colors in early-eighteenth-century China. *Journal of Glass Studies* 64: 147–167, <https://www.jstor.org/stable/48703407>.
- COLOMBAN, Philippe. 2020. Glaze and enamels. In *Encyclopedia of glass science, technology, history and culture*, ed. Pascal RICHET, 1309–1326. Hoboken, N.J.: The American Ceramic Society and John Wiley and Sons Inc. <https://doi.org/10.1002/9781118801017.ch10.6>
- COLOMBAN, Philippe, Florian AMBROSI, Anh-Tu NGO, Ting-An LU, Xiong-Lin FENG, Stephen CHEN, and Chung-Lit CHOI. 2017. Comparative analysis of *wucaï* Chinese porcelains using mobile and fixed Raman microspectrometers. *Ceramics International* 43(16): 14244–14256, <https://doi.org/10.1016/j.ceramint.2017.07.172>.
- COLOMBAN, Philippe, Michele GIRONDA, Divine VANGU, Burcu KIRMIZI, Bing ZHAO, and Vincent COCHET. 2021. The technology transfer from Europe to China in the 17th–18th centuries: Non-invasive on-site XRF and Raman analyses of Chinese Qing Dynasty enameled masterpieces made using European ingredients/recipes. *Materials* 14(23): 7434, <https://doi.org/10.3390/ma14237434>.
- COLOMBAN, Philippe, Burcu KIRMIZI, Catherine GOUGEON, Michele GIRONDA, and Catherine CARDINAL. 2020. Pigments and glassy matrix of the 17th–18th century enamelled French watches: A non-invasive on-site Raman and pXRF study. *Journal of Cultural Heritage* 44: 1–14, <https://doi.org/10.1016/j.culher.2020.02.001>.
- COLOMBAN, Philippe, Anh-Tu NGO, and Nicolas FOUNERY. 2022. Non-invasive Raman analysis of 18th century Chinese export/armorial overglazed porcelain: Identification of the different enameling techniques. *Heritage* 5(1): 233–259, <https://doi.org/10.3390/heritage5010013>.
- COLOMBAN, Philippe, Gulsu SIMSEK FRANCI, and Burcu KIRMIZI. 2021. Cobalt and associated impurities in blue (and green) glass, glaze and enamel: Relationships between raw materials, processing, composition, phases and international trade. *Minerals* 11(6): 633, <https://doi.org/10.3390/min11060633>.
- COLOMBAN, Philippe, Gulsu SIMSEK FRANCI, Michele GIRONDA, Pauline D'ABRIGÉON, and Anne-Claire SCHUMACHER. 2022. pXRF data evaluation methodology for on-site analysis of precious artifacts: Cobalt used in the blue decoration of Qing dynasty overglazed porcelain enameled at Custom District (Guangzhou), Jingdezhen and Zaobanchu (Beijing) workshops. *Heritage* 5(3): 1752–1778, <https://doi.org/10.3390/heritage5030091>.
- COLOMBAN, Philippe, Gulsu SIMSEK FRANCI, Jacques BURLLOT, Xavier GALLET, Bing ZHAO, and Jean-Baptiste CLAIS. 2023. Non-invasive on-site pXRF analysis of coloring agents, marks and enamels of Qing imperial and non-imperial porcelain. *Ceramics* 6: 447–474, <https://doi.org/10.3390/ceramics6010026>.
- COLOMBAN, Philippe, Yizheng ZHANG, and Bing ZHAO. 2017. Non-invasive Raman analyses of huafalang and related porcelain wares: Searching for evidence for innovative pigment technologies. *Ceramic International* 43(15): 12079–12088, <https://doi.org/10.1016/j.ceramint.2017.06.063>.
- CURTIS, Emily B. 2019. Aspects of a multi-faceted process: The circulation of enamel wares between the Vatican and Kangxi's court. *Extrême-Orient Extrême-Occident* 43: 29–39, <https://doi.org/10.4000/extrêmeorient.2168>.
- EDWARDS, Howell G. M., Peter VANDENABEELE, and Philippe COLOMBAN. 2023. *Raman spectroscopy in cultural heritage preservation*. Heidelberg, Germany: Springer Cham. <https://link.springer.com/book/10.1007/978-3-031-14379-3> (accessed 20 December 2024).
- KINGERY, Walter D., and Pamela B. VANDIVER. 1986. The eighteenth-century change in technology and style from the *famille-verte* palette to the *pamille-rose* palette. In *Technology and style*. Vol. 2, ed. Walter D. KINGERY, 363–381. Columbus, Ohio: The American Ceramic Society.
- MONTANARI, Riccardo, Maria Francesca ALBERGHINA, Anna CASANOVA MUNICCHIA, Emilio MASSA, Alberto PELAGOTTI, Claudia PELOSI, Salvatore SCHIAVONE, and Alberto SODO. 2018. A polychrome Mukozuke (1624–1644) porcelain offers a new hypothesis on the introduction of European enameling technology in Japan. *Journal of Cultural Heritage* 32: 232–237, <https://doi.org/10.1016/j.culher.2017.12.010>.
- MONTANARI, Riccardo, Nobuyuki MURAKAMI, Philippe COLOMBAN, Maria Francesca ALBERGHINA, Claudia PELOSI, and Salvatore SCHIAVONE. 2020. European ceramic technology in the Far East: Enamels and pigments in Japanese art from the 16th to the 20th century and their reverse influence on China. *Heritage Science* 8: 48. <https://heritagesciencejournal.springeropen.com/articles/10.1186/s40494-020-00391-2> (accessed 19 December 2024).

- SHIH, Ching-Fei. 2007. Evidence of East–West exchange in the eighteenth century: The establishment of painted enamel art at the Qing court in the reign of Emperor Kangxi. *National Palace Museum Research Quarterly* 24(3): 45–94.
- SHIH, Ching-fei, 2021. *Hua Falang*: The Chinese concept of painted enamels. In *The RA collection of Chinese ceramics: A collector's vision*. Vol. 5, ed. Maria Antonia PINTO DE MATOS, 28–59. London: Jorge Welsh Research & Publishing.
- SHIH, Ching-Fei. 2022. L'avènement d'une nouvelle palette de couleurs à Jingdezhen au XVIIIe siècle. In *Le secret des couleurs: Céramiques de Chine et d'Europe du XVIIIe siècle à nos jours*. Ed. Pauline D'ABRIGEON, 21–59. Milan, Italy: 5 Continents Editions & Fondation Baur.
- WANG, Meg C. 2022. Eighteenth-century Chinese painted enamelware materials and techniques. *Baur Foundation Bulletin* 80: 24–53.
- XU, Xiaodong. 2015. Europe-China-Europe: The transmission of the craft of painted enamel in the seventeenth and eighteenth centuries. In *Goods from the East, 1600–1800 trading Eurasia*, ed. Maxime BERG. London: Palgrave Macmillan, 92–106.
- ZHANG, Fukang. 1985. The origin and development of traditional Chinese glazes and decorative ceramic colors. In *Technology to modern science*. Vol. 1, ed. Walter D. KINGERY, Ceramics and Civilization Series, 163–180. Columbus, Ohio: The American Ceramic Society.