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The Composition and Technology of Polychrome Enamels on Chinese Ruby Backed Plates Identified Through Non-destructive Micro-X-Ray Fluorescence

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Abstract

This research presents non-destructive analyses of Chinese enamelled copper and porcelain decorated with polychrome enamels. This study utilizes two key, high value art works with complex enamelling in the collection of the Victoria and Albert Museum (London, United Kingdom) to elucidate the composition and technology of objects with ruby backed decoration. These plates date from early Qing dynasty, and are associated with the Yongzheng (1723-1735) and early Qianlong (1735-1796) periods. The goal of this research is to investigate the hypothesis that ruby backed plates in these two mediums are decorated with the same enamels, and possibly manufactured in mutual enamelling workshops which is a current topic of debate among scholars. Ten different enamel colours and the gilding on each plate were analysed and evaluated with micro-X-Ray fluorescence to study the opacifiers and pigments. The results show that the enamels on these two works utilise the same opacifier, and the consistent pigments in the white, ruby, pink, green, yellow, turquoise green and blue enamels. Compositional differences were identified in the underdrawings, purple enamels and gilding. The results demonstrate that Chinese painted enamels and overglazes on porcelain share mutual technology in most, but not all, of the polychrome decoration which impacts upon our knowledge of technological organisation in the manufacture of these objects. Micro-X-Ray fluorescence has been shown to be an effective and robust technique for the non-destructive study of decorative surfaces in these two material types.

Key Words: Chinese Painted Enamel, Art Conservation, Porcelain, Enamelled Copper, X-Ray Fluorescence

Introduction

In 2017 a project was started to compare the compositions of the enamel decoration on 18th century Chinese objects in the collection of the Victoria and Albert Museum. Two specific objects are of interest because they have nearly identical motifs and appearances but are made in fundamentally different mediums: porcelain and enamelled copper. The plates are referred to as "*ruby-backed*" due to the reverse being enamelled in vivid transparent pink on the underside of the rim. Each object has been meticulously hand painted with fired on polychrome enamels depicting a central figurative scene. The rims are both embellished with registers containing diaper patterns, and reserve panels featuring fruit and flora. Ruby-backed plates are highly prized historical art objects because this style of decoration is associated the Yongzheng period during the early part of the Qing dynasty and thus considered to be exceedingly rare.

Both ruby-backed plates are attributed to the early part of the 18th century by the museum, the porcelain is dated to 1730-40 [1]. Whereas, the copper dish is ascribed a slightly wider period of 1730-1770 [2]. These finely painted objects produced within a few decades of each other on different sub-surfaces advocated a closer look into their technological processes in order to assess innovation strategies and the extent of variation in these high-quality productions. The date of pieces with the ruby-backed pattern is important because it places them just after the introduction of the "*famille rose palette*", and the inception of the artistic tradition of Chinese painted enamels [3]. Due to their similarity in appearance, these objects have been used by historians in a sequence of publications to illustrate the relationship between overglaze enamel decoration on Chinese porcelain and Chinese painted enamels on metal [4–6].The importance of these key cultural objects has been discussed before, and a clear compositional analysis would generate significant implications for our understanding of enamel technology in terms of development and manufacture.

Figure 1: Chinese Painted Enamel dish on copper, 20.5 cm in diameter
©Victoria and Albert Museum, Accession Number C.107-1931

Figure 2: Chinese porcelain dish with overglaze enamel decoration, 21.1 cm in diameter
©Victoria and Albert Museum, Accession Number C.28-1912

Early Qing objects are rare and typically of very high quality making sampling and destructive analysis of pieces in good condition inappropriate. Scientific analysis of early Qing period porcelain is particularly limited by this context, and only a few studies have been published with quantitative data on these enamels [7,8]. In 1999 a project using a non-destructive analytical technique on pink enamels was carried out by Rose Kerr and Paula Mills at the V&A. Their research focused on the pink overglaze enamels used to decorate Chinese porcelain and the ultimate origin of the colour's technology. The project resulted in two papers in which pink enamels from Chinese porcelains, glass and painted enamels are compared to those from Meissen, Chelsea, Sèvres and Mennecy porcelains [5,9]. Pinks from forty-eight objects were analysed using X-Ray Fluorescence, and it was concluded that the pink enamels on the Chinese painted enamel objects (or Canton enamels as they are often referred to) were most similar to the overglaze enamels on Chinese porcelain. The results of their study remain however inconclusive regarding the ultimate origin of the technology used in early pink Chinese overglaze enamels on porcelain in the 18th century, due to the limitations of the available analytical technique. However, this research provided an interesting observation regarding the absence of tin in the 18th century Chinese examples, indicating that Au-Sn pink, which was established in Europe at that time, may not have been employed in Chinese porcelains until the 19th century [5]. There have only been two additional compositional studies published for Chinese painted enamels. The first employed micro-EDXRF to analyse five colours from a Chinese painted enamel in the Beijing Place Museum collection, and the second ESEM-EDX data for four colours from an armorial object in the collection of the Ashmolean museum [10,11]. Elemental analysis with Micro-X-Ray Fluorescence creates an opportunity to study the compositions of the enamel colours in ruby-backed plates non-destructively. The analysis can be done quickly while targeting small areas of decoration. By analysing as many of the enamel colours as possible between these two pieces under the same conditions, a direct comparison of their technology can be made and generate new insights into these rare historical objects.

Material and Methodology

In order to understand the compositional relationship between the enamels used to decorate both the porcelain plate C.28-1912 and the painted enamel plate C.107-1931, µXRF was employed for its analytical robustness and high resolution capabilities. Analysis of the surface decoration and different coloured enamels will be used as a proxy to evaluate the level of similarity in technology between Chinese porcelain and painted enamels on copper. The objects in this study are both fine and rare examples of Chinese decorative arts, therefore only non-destructive techniques are plausible options for the study of their composition making X-ray Fluorescence analysis a very suitable technique.

XRF has been used extensively in the study of art and archaeological objects and produces qualitative and more rarely quantitative elemental analysis for elements ranging in mass from Al to U (and with certain set ups magnesium and sodium) [12,13]. In this project the use of µXRF has significant advantages over other types of equipment (such as portable varieties) given a much smaller spot size which can be focused on an area of ~0.2mm, precise enough to analyse the individual lines in the decoration. The technique has practical limitations in that the object must be able to fit inside the machine (approx. 400x300mm and 200mm height), and that the surface for analysis must be relatively flat so it can be raised within 30-10mm of the detector. Both plates measure approximately 21cm in diameter and sit comfortably on the internal stage. The rim of each of these objects has roughly a twenty degree angle, thus restricting analysis to the outer 1cm of the rim and the underside of the base. A Seiko SEA6000 benchtop Micro-XRF was used to carry out the analysis, utilizing a helium purge with a measurement time of 60 seconds at 50kV and 1000µA for all analyses. The analyte area was set to 0.5mm and no filters were used. The machine is equipped with an internal sensitive high magnification digital camera which is used to target the analysis spot on the surface of the object. An image of the area analysed is automatically captured and recorded. Two or three analyses were conducted for each colour that was accessible on both objects. The elements present in each area were recorded qualitatively.

In order to accurately interpret the results of this study, it is important to note that the painted decoration is thin enough that the underlying substrate contributes to the fluorescence detected by the machine [12]. The undecorated glaze on the porcelain plate and the white enamel on the copper plate have been presented for comparison to the upper layers of enamel and gilding. When applying the painted enamel decoration, the pattern was first set out in a brown underdrawing, followed by the polychrome enamels and then the gilding was applied in a final step. Ten colours were selected for analysis on these objects: white, ruby, pink, blue, yellow, purple, green, turquoise green, gilding and the brown underdrawings. Several colours were however only analysed on the porcelain plate due to time constraints and differences in the colour palettes. These include: fine outlines in black and red, and brown and turquoise blue enamel.

Results

Elements with characteristic Kα/Kβ or Lα/Lβ peaks in the spectra were identified, and instrument artefacts accounted for by comparison with a lead glass standard DLH2 which closely matches the elements of interest for this study [14,15]. The results of the study are presented as intensities in Table 1. Previous tests demonstrated that the copper body of C.107-1931 would fluoresce through the enamel layers, thus 500 counts associated with this element have been removed from the table as they do not represent accurately the amount of copper in the enamel.

Discussion

This discussion follows the structured layering of the objects starting with the white enamels and underdrawings, which are applied before the polychrome decorations.

White Enamels

In Chinese painted enamels on copper, white is most commonly used as the ground layer which coats the metal surface. White is very rarely used in these objects as a painted enamel colour, it only occasionally appears as small highlights in Chinese painted enamels decorated with a lotus pattern on turquoise ground which emulates cloisonné [16]. In this example small white painted enamel dots encircle the rim. The compositions of the white enamels are particularly important because of the colour's role in the development of the *famille rose* palette in the early 1720's. Technical changes seen in the 18th century not only involved the addition of this colour, but also the ability to control opacification across the colour palette [17]. The white enamel could be mixed with translucent colours to create pastel shades of varying opacity.

As expected, the results confirm that both the white enamels in this study are high lead silicate glasses opacified with arsenic (As). Potassium (K) and zinc (Zn) are present in both objects alongside low levels of aluminium (Al) and iron (Fe). A trace amount of copper (Cu) was detected in the overglaze enamel on the porcelain, but not in the enamel from the copperware dish. The absence of a trace amount of Cu in the white from the painted enamel is most likely due to counts being removed from this element to compensate for the copper body of the vessel. The use of As as an opacifier is consistent with17th century Venetian glass [18–20]and inconsistent with the technology of French and German white enamels, which are based on tin (Sn) oxide [21].

Underdrawings

The underdrawing is the first stage of applying the enamel decoration in both objects. The underdrawing is used to set out design elements such as the banding which defines registers, the borders of the reserve panels and key aspects of the motifs such as the figures. Both underdrawings have dry granular appearances under magnification; the appearance is consistent with hematite (Fe_2O_3) ground into a fine powder and suspended in an aqueous solution with an organic binder, rather than the glassy appearance of vitrified enamels prepared from cakes. Once the underdrawing was painted it could be fixed by firing which would allow the polychrome enamels to be painted over the design without disturbing the pattern [22].

Important variations can be seen between the compositions of the underdrawings, although both are clearly based on Fe. The underdrawing on the porcelain plate is mainly based on Al, Ca, Ti, Mn, Fe, Zn and traces of Sr. Although Al, Ca and Ti are present in the glaze substrate, they are not detected at these intensities in the other enamel colours. Mn and Fe were detected at higher levels than the glaze, Zn and Sr are not present in the glaze. In contrast the underdrawing on the copper vessel is based on Fe associated with a trace amount of Cu. Fe counts are approximately five times higher in the underdrawing on the porcelain plate accompanied by Al as observed by Kingery and Vandiver [7]. Whereas the underdrawing on the enamelled copper plate less complex composition based on Fe. The differences in the compositions of the underdrawings indicate a divergence in technology which maybe necessitated by their respective substrates.

Yellow Enamels

Under magnification it is obvious that the yellow painted enamel on the copper plate is translucent and flush with the surface; in contrast the yellow overglaze on the porcelain plate is opaque and sits proud of the glaze. The areas analysed on the porcelain plate are the flowers on the rim; the yellow spectra on the enamelled copper plate is from the gourd in the motif painted inside the foot ring. Yellow painted enamels on copper objects are typically translucent rather than opaque, whereas both can be found on porcelain. As with white painted enamels, opaque yellow is used as a highlight in painted enamels on copper with the lotus pattern on a turquoise ground, but objects with this decoration are rare. The difference in opacity is an important distinction because opaque yellow is also considered to be one of three new overglaze enamel colours introduced in the 18th century [23][21].

Figure 3: Yellow Painted Enamel and Overglaze Enamel under magnification

The yellow enamels in this study are both pigmented with Sn accompanied by Zn. On the enamelled copper dish As is present in the white enamel layer below the yellow painted enamel. There is a reduction of As counts by roughly three quarters in this enamel, indicating that arsenic is not a part of the composition of the yellow painted enamel on the copper vessel. The use of Sn as a colourant is consistent with Chinese cloisonné enamels and overglaze yellows on porcelain [24–26]. The two yellow enamels are very similar in composition, and it is assumed that the opaque overglaze was achieved by mixing the translucent yellow overglaze enamel with white [17,23,27].

Green and Turquoise Enamels

The V&A plates each have floral decoration with leaves painted in the two distinct tones, a vibrant green and a cooler turquoise green. These enamels are translucent and similar visually under a microscopic. A third shade, turquoise blue, is only present on the porcelain plate as the ground in the 1cm wide register at the rim. Turquoise blue has been included in Table 1 for comparison to the green and turquoise green enamels.

Like the yellow enamels, the warmer greens include Sn and Zn, the green colour is due to the addition of Cu. The peak intensities of Sn are similar between the warm green and yellows, but the Zn peaks are roughly four times higher in the warm greens and was possibly added as an opacifier [28]. Tin is absent in the cooler turquoise green enamels and the Zn peaks increase up to ten times that of the yellows. The peak intensities for Fe increase by roughly a third between yellow and the warm greens, and double that of the yellows in the turquoise greens. Copper peak intensities also double between the warm greens and the turquoise greens. Arsenic is present in the warm green overglaze enamel but absent in the turquoise green on the porcelain plate. The presence of As in the copper plate is most likely due to the composition of the white enamel substrate fluorescing through the painted layer. When comparing the greens to the turquoise greens, the colour changes from warm to cool by: removing Sn and As, adding a small amount of Fe, and significantly increasing the amount of Cu and Zn.

Although the turquoise blue overglaze enamel has only been used to decorate the porcelain plate, the analysis of this colour has been included to show the subtle change in composition used to produce pastel hues in the palette. In comparison to the other enamels: Fe is reduced to level similar to the yellows, Cu is half that of the warm greens, Zn falls halfway between yellow and warm green, As is double that of the opaque yellow and Sn is absent. The colour of the overglaze turquoise blue appears to be influenced by the addition of As which changes it to a pastel shade. Subtle differences in the proportion of the colorants between green, turquoise green and turquoise blue reveals a high level of understanding and control over the composition of these enamels.

Blue Enamels

The two blue enamels are both found in floral elements on the rims. The blues are of a similar hue, but under magnification it is obvious that the blue on the porcelain plate sits proud of the surface, is transparent and is crazed. Crazing is a network of cracks caused by the difference in contraction between the enamel layer and its substrate during cooling, or by subsequent expansion of the substrate which could include the firing of additional colours during manufacture [22].

Figure 4: Blue Painted Enamel and Overglaze Enamel under magnification

A combination of Ca, Mn, Fe, Co, Ni, Zn, As and barium (Ba) were detected in both blue enamels. At first glance the blue compositions appear to be very similar, however when considering the substrates, the challenges of associated with non-destructive analysis of layered surfaces are highlighted. We can be sure that the overglaze enamel is based on Mn, Fe, Co, Ni, Zn, and Ba because these elements are not present in the glaze or the white enamel on the copper vessel. Ca and As are more complicated because of their presence in the porcelain glaze and white enamel substrate of the copper vessel respectively. The presence of As is particularly important because of its association with European cobalt sources [29–31]. When comparing the spectra, the compositions of the two blue enamels are very similar, and both are low Mn which is inconsistent with Chinese cobalt sources [32,33].

Ruby and Pink Enamels

The ruby enamels on the back of each of the plates, and pink enamels from the floral motifs on the rims are compared in this study. In appearance the ruby enamels are both more intense shades than the two pinks, and both have been applied evenly across the surface. The ruby enamel on the back of the porcelain plate has a slightly textured surface similar to orange peel; this enamel also appears to be slightly more opaque in comparison to the ruby back of the copper plate. In contrast the ruby enamel on the back of the copper plate has a glossy surface texture; the colour is vibrant and is a visibility translucent layer over the white enamel substrate. The pink enamels used in the floral elements at the rims both appear to be thinner applications, painted in such a way as to create gradation from a pale pink to a deeper colour nearer that of the ruby enamel. The effect on the enamelled copper plate is similar in appearance to washes of water colour, whereas the overglaze pink is more homogeneous.

The spectra for the two ruby enamels on the backs of the plates are nearly identical in composition and peak height. These enamels are pigmented with gold (Au) and have with distinct Zn peaks. Pb and As are clearly higher in the ruby enamel on the copper plate due to the white enamel substrate, and there is increased aluminium (Al) in the ruby on the porcelain plate, which is likely associated with the glaze. Apart from these observations, the elemental composition in both objects appears to be consistent across the pink and ruby enamels. These results confirm that the ruby and pink enamels have very similar compositions, and that the method and or thickness of application is responsible for the difference in their appearance. Interestingly Sn, which is often associated with 18th century European pinks, is absent in these compositions. Pink enamels which do not include tin were produced in China and Europe during this period [5,23].

Purple Enamels

The purples both serve as the ground in the diaper pattern on the rims, these two enamels differ in colour. In this section the opaque enamel on the copper plate is referred to as mauve, and the translucent enamel on the porcelain plate is referred to as lavender for clarity. Analysis of the two purple enamels revealed that they differ in composition as well as appearance. The mauve painted enamel on the copper plate is Mn and Fe based with reduced As peak intensity when compared to the white enamel substrate. Manganese used to create the mauve shade of purple on the enamelled copper plate is consistent with Chinese cloisonné[25] and Limoges painted enamels [34–36].

A combination of colloidal gold with low to trace levels of Mn, Fe, Co and Cu was detected in analysis of purple overglaze enamels in studies by Kingery and Vandiver [7], and Giannini [8]. Cobalt, Zn and As were the only colourants detected in the pastel lavender shade on the porcelain. It is assumed that the pink hue of the lavender overglaze enamel was achieved by mixing white, pink and blue overglaze enamels. However, it is not possible to establish the presence of trace amounts of gold in a high lead matrix with this analytical technique.

Outlines

Outlines in black, blue and red from the porcelain plate were analysed these are situated mostly on the porcelain plate rather than the enamelled copper plate. These colours are fine opaque lines applied over the polychrome overglaze enamels. The two black outlines on the porcelain are different in appearance, the first is a matt banding line adjacent to the gilt rim of the plate, the second a vitrified detail from the veining painted on one of the turquoise green leaves. The black band at the rim has an unusually high magnesium (Mg) peak compared to the other enamels on this object, high Al and Ca; the colour is based on a combination of Ti, Fe, Co, Ni, Cu and Zn. The black outline on turquoise leaf is based on Fe, Co, Ni, Cu and Zn, only the Co and Ni differ significantly in peak intensity from the turquoise green layer below.

The blue outline has been used to create the diaper pattern in the turquoise blue and lavender registers at the rim of the plate. The red outline is used to create the hexagonal and square shapes within this pattern. The analysis spot of the blue outline is within the turquoise blue register, and the red outline in the lavender register. Mg, Fe, Co, Cu, Zn and As were detected in the blue outline, the spectra differs from the turquoise blue ground by the presence of Mg, Co, As and a reduction of Zn by more than half. This suggests that the blue outline is based on Mg, Co, and As; Fe and Cu may also play a role in the colour because the peak intensities are not reduced as seen with Zn. The red outline is based on Ca, Mn, high Fe, Cu, Zn and As; each of these elements are either absent or have significantly lower peak intensities than the lavender layer below. The red outline is distinct from the brown underdrawing in that it has higher Fe and Zn, Cu and As are present, Mn and Ca are lower, Ti is absent and Al is not elevated above the level seen in the polychrome overglaze enamels.

Gilding

In this study the gilding on the edge of the rim on the porcelain plate is compared to the gilding surrounding one of the blue floral medallions within the register on rim of the copper plate. Fired on gilding is applied at a lower temperature than the polychrome enamels, and therefore adds to the production costs, labour and status of these objects. Both gilding examples have a slightly distressed and textured appearances under magnification. The compositions of the gilding are both based on Au associated with low levels of silver (Ag) and Mn. Fe was also detected in both examples of gilding although the peak intensity was three times higher in the gilding on the porcelain plate. Other differences are seen in the presence of Ca and Cu alongside elevated levels of Al in the porcelain plate. The absence of Cu in the gilding on the enamelled copper vessel may be due to the difficulties associated with this material and analytical technique.

Conclusion

In this study the compositions of polychrome enamels used to decorate two rare and important ruby-backed plates in the collection of the Victoria and Albert Museum have been evaluated. The materials analysed include ten enamel colours, four outlines, the underdrawings, and the gilding. The aim of the project was to investigate the theory put forward by past researchers that the technology of the enamels used to decorate these objects is likely the same despite differences between the porcelain and copper subsurfaces. In the past links between their technology have been based on the similarity of their motifs, visual examination and historic documents because very little has been published on the composition of Chinese painted enamels on copper. In this paper the compositions of the green, turquoise green, purple and gilding from a Chinese painted enamel object have been presented for the first time to substantiate an analytical dataset for this material.

The results confirm that the white, green, turquoise green, pink and ruby enamels employ the same technology to achieve these colours. The blue enamels are also very close in composition, but due to limitations of the technique and the layered nature of the surface, it is not possible to determine if the As detected in the painted enamel is part of this layer or its substrate. The yellow enamels are also very similar in that they are both based on Sn, but the overglaze enamel has been intentionally opacified with As. The yellow painted enamel on the copper vessel appears to be a translucent colour, although interpretation of this spectra is also complicated by As in the white enamel substrate.

On the other hand, a clear compositional difference can be seen between the two purple enamels, with the painted enamel based on Mn, and the overglaze enamel being pigmented by Co, Ni and possibly Au. There are also substantial differences in the compositions of the underdrawings and the gilding. In both of these materials the decoration on the porcelain plate utilises a wider range of elements. Historians have debated whether ruby-backed plates in these two mediums were produced in a mutual workshop by the same artists, where the production centres were, and if the technology was transferred from painted enamels to overglazes on porcelain. The outcome of this study confirms a strong technological link in the opacifiers and pigments in Chinese painted enamels and overglaze enamels in the first half of the 18^{th} century, but it also highlights a few key differences in composition. Opacification of yellow overglazes and increased alumina in the underdrawing on the porcelain plate is required to achieve the desired colour on the glaze substrate. Compositional differences in the two purples could represent a decorative choice, or the availability of enamel colours at the time of manufacture. The more complex composition of the gilding on the porcelain plate could also represent changes in production due to a lapse of time and resources, or manufacturing requirements related to the glaze substrate.

This study has demonstrated the effectiveness of micro-X-ray fluorescence to identify opacifiers and pigments in polychrome enamel decoration on Chinese porcelain and copper objects. The technique is particularly useful for the study of high quality art objects because small areas of the finely painted enamel decoration can be targeted with the internal high magnification digital camera. The relationship between these two artistic traditions will undoubtedly be studied further in the future, as access to precision non-destructive analytical equipment becomes more widely available for the study of museum collections.

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Object	Colour	Na Kα	Mg Kα	Al Kα	Si Kα	K Kα	Ca Kα	Ti Kα	Mn Kα	Fe Kα	Co Kα	Ni Kα	Cu Kα	Zn Kα	As Kβ	Sr Kα	Nb Kα	Ba Lα	Ag Kα	Sn Kα	Au Lα	Pb Lα
C.28-1912 Porcelain	Black Outline 1, 5mm		8524	408	2152	1549	1442	317		6051	1858	282	133	236				1				2750
C.28-1912 Porcelain	Black Outline 2, 5mm		1	88	3033	1757				357	159	165	10131	5737								41583
C.28-1912 Porcelain	Blue Outline 1, 5mm		265	67	3208	1966				355	139		10121	1823	1999							50342
C.28-1912 Porcelain	Blue 1, 5mm			60	3075	1150	195		41	1004	1658	632		445	1460			54				34527
C.28-1912 Porcelain	Blue 2, 5mm		35	66	3131	1219	201			1078	1688	631		449	1436			54				34326
C.28-1912 Porcelain	Underdrawing 1, 5mm			152	2472	1338	1212	83	413	11383				154		92	35					4520
C.28-1912 Porcelain	Brown 1, 5mm			91	2848	1710		36	947	7219			679	1416	771					81		32953
C.28-1912 Porcelain	Brown 2, 5mm		792	90	2786	1473		26		6236			549	1149	594					61		26798
C.28-1912 Porcelain	Gilding 1, 5mm			212	1812	564	405		123	1292			107						273		14341	3788
C.28-1912 Porcelain	Gilding 2, 5mm			211	1618	560	368		113	1263			126						293		14856	3780
C.28-1912 Porcelain	Green 1, 5mm			82	3503	1515				234			3966	2352	324					36		33671
C.28-1912 Porcelain	Green 2, 5mm			87	3488	1502				221			3758	2218	313					36		32889
C.28-1912 Porcelain	Green 3, 5mm			90	3536	1551				194			3958	2424	334					27		36736
C.28-1912 Porcelain	Pink 1, 5mm			74	2899	632				144				570							290	26180
C.28-1912 Porcelain	Pink 2, 5mm			65	2901	639				146				575							301	26688
C.28-1912 Porcelain	Pink 3, 5mm			74	2930	665				134				545							280	26561
C.28-1912 Porcelain	Purple 1, 5mm			42	2719	975				161	127			836	1744							39207
C.28-1912 Porcelain	Purple 2, 5mm			35	2683	988				146	92			775	1696							38480
C.28-1912 Porcelain	Red Outline 2, 5mm			59	2421	1851	293		99	13194			86	1046	2220							49954
C.28-1912 Porcelain	Ruby 1, 5mm			116	4029	1118			53	192				820							427	37555
C.28-1912 Porcelain	Ruby 2, 5mm			124	4049	1120			52	192				821							431	37417
C.28-1912 Porcelain	Ruby 3, 5mm			117	3999	1092			62	216				798							426	36036
C.28-1912 Porcelain	Turqouise Blue 1, 5mm			39	2367	927				143			1817	993	1375							33634
C.28-1912 Porcelain	Turqouise Green 1, 5mm			128	4159	1834				365			10197	5746								40840
C.28-1912 Porcelain	Turqouise Green 2, 5mm			126	4178	1808				356			10120	5697								40737
C.28-1912 Porcelain	White 1, 5mm			48	2845	1064				174			91	900	1773							38232
C.28-1912 Porcelain	White 2, 5mm			37	2778	1003				160			70	850	1585							35540
C.28-1912 Porcelain	Yellow 1, 5mm			117	4277	2120				149			20	582	852					88		50696
C.28-1912 Porcelain	Yellow 2, 5mm			97	3883	2053				137				536	765					87		49205
C.28-1912 Porcelain	Yellow 3, 5mm			87	3726	1969				183			24	564	713					107		44992
C.107-1931 CPE	Blue 1, 5mm			58	2135	938	226		176	1335	1642	791		692	2002			150				54048
C.107-1931 CPE	Blue 2, 5mm			49	2160	881	223		172	1402	1811	874		756	1963			152				51919
C.107-1931 CPE	Underdrawing 2, 5mm			42	1445	1320				2244			11		2402							65442
C.107-1931 CPE	Gilding 1, 5mm			50	700	469			68	488									39		13324	37181
C.107-1931 CPE	Gilding 2, 5mm			47	737	477				294									20		11744	38982
C.107-1931 CPE	Green 1, 5mm			62	1785	1500				256			2879	2366	948					93		46419
C.107-1931 CPE	Green 2, 5mm			57	1709	1780				359			4415	3307	1257					1		54266
C.107-1931 CPE	Pink 1, 5mm			67	1986	1254				400				1104	1153						630	49389
C.107-1931 CPE	Pink 2, 5mm			46	1480	1050				279				903	1095						420	44679
C.107-1931 CPE	Purple 1, 5mm			57	1219	1766			1602	10758					1457							52048
C.107-1931 CPE	Purple 2, 5mm			51	1531	1243			1062	612					1821							56963
C.107-1931 CPE	Ruby 1, 5mm			76	2444	1253				165				919	1155						441	49568
C.107-1931 CPE	Ruby 2, 5mm			59	2040	1202				195				1041	1108						522	49026
C.107-1931 CPE	Turqouise Green 1, 5mm			58	1771	1655				316			6954	4966	1121							44912
C.107-1931 CPE	Turqouise Green 2, 5mm			43	1427	1299				341			7921	5200	674							36504
C.107-1931 CPE	White 1, 5mm			35	1834	1198				142					2134							56971
C.107-1931 CPE	White 2, 5mm			38	1466	1256			102	203			64		2379							64691
C.107-1931 CPE	Yellow 1, 5mm			53	1708	1482				127				518	522					34		45617
C.107-1931 CPE	Yellow 2, 5mm			46	1287	1163				170				458	975					100		40936
DLH2 Feb 8th 2017	Blue spot size 5mm	BD	3	189	3402	675	892			1106	743									431		39017
DLH2 Feb 9th 2017	Blue spot size 5mm	BD	3	204	3793	780	1025			1260	863									443		43745
DLH2 Feb 9th 2017	Blue spot size 5mm	BD	1	66	1355	686	944			1279	884									459		45685
DLH2 (Mean Oxide %)	Blue	7.34%	0.89%	4.15%	40.05%	2.79%	2.88%			0.91%	0.39%									4.06%		36.36%

Table 1: Results from micro-XRF analysis of enamels on Porcelain Dish C.28-1912 and Painted Enamel on Copper Dish C.107-1931 presented as intensities. BD= Below Detection