19th century ornamented metal trays from Greece and Turkey: metallurgy and provenance

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Abstract

Twelve ‘Japanned’ metal trays from Greece and Turkey, dated in the 19th century, were subjected to macroscopic and microscopic examination (stereoscopy, metallography, scanning electron microscopy) as well as to XRF and SEM-EDX analysis. The trays represent two stylistic types made of wrought iron either tin-plated or protected with a primer. Two were manufactured by forging while the rest were made by rolling prior to die forming with drop hammers or machine presses. Wrought iron was produced indirectly from cast iron with fossil fuels. Only in one case charcoal fuel was implied. Most pure iron was recognized for four trays dated at the end of the 19th century. Three of them also revealed the deliberate incorporation of metallic manganese while one of them was found to be alloyed. The other metals used such as copper, brass, silver and tin as also the methods applied, seem to follow the industrial evolution of the iron substrate but more analysis is required. As regards origin, the metallurgical results, even limited, combined with historical information, indicated that the metals/techniques used, were probably originally produced in west Europe although the supply of materials could have depended on different sources.

Introduction

On the occasion of the exhibition ‘Rituals of hospitality: Ornamented trays of the 19th century in Greece and Turkey’, which was held in the Benaki Museum of Athens, Greece, in 2012, the conservation department of the museum had the opportunity to investigate a small group of these artifacts and in particular the materials and manufacture techniques applied.

The exhibition which was organized by the curators Flavia Nessi and Myrto Hatzaki, in collaboration with the Benaki Museum, was dedicated to the history of these ornamented trays which were familiar and popular in the newly established Greek state and the Ottoman Empire at that time. Almost two hundred trays were gathered either from museums or private collections, houses and antique shops. These were every day metal objects of quality used for the serving of sweets and drinks to guests. They were either hand painted or printed, presenting images of kings and queens, beautiful ladies, flowers, fruits and urban landscapes. However despite their popularity, these artifacts had been little studied (Nessi and Hatzaki, personal communication) while at the same time several texts (Koppelin, 2010; Jones, 2012), have been carried out on corresponding European products, industries or workshops by throwing new light into the history of the decorated trays in Europe of the 18th and 19th century.

Therefore, painting on metal has been known in Europe since the 16th century especially for small pictures called ‘cabinet’ pictures. At the same time however another technique prevailed according to its beautiful aesthetic results. It was the famous japan technique, originated from the Far East which led to the establishment of several factories such as the Pontypool Japan Works and the Gouverhanton in Britain (1730 and 1760 respectively), the Venice Martin in France (1770, Jones, 2012: 280-283; (Guéné, 2013: 165-201) and finally the W. Stobwasser in Germany (1770) which affected not only rival companies such as the W. Stockmann & Co. (also in Germany, Kopplin, 2010: 206-207) but foreign countries as well such as Russia (1795) with an export activity in Persia (Hatzaki and Nessi, 2013: 15-95).

This layer was composed of a) a black or colored ground, usually an organic mixture applied in several coats which was then stoved and polished, b) the painting (composed by pigments and a transparent ‘mixing varnish’) or later the printing (transfers or degals and decoupage) c) the protective copal varnish which was baked in a stove and polished (Guéné, 2013: 165-201). Equally important to the development of this technique was the improvement of the manufacture and surface properties of the metallic substrate. This need led to the utilization of tin plating over iron-
sheet providing protection to the underlying layer and to the discovery of the rolling mill which ensured a smooth surface to receive tin plating. Later on, it also led to the replacement of tin for steel in parallel with the application of drop hammers, screw- and hydraulic- presses for mass production (Jones, 2013: 133-147). The handles were made by casting in molds while their surface according to Guéné (2013:165-201) bore printing decoration.

In the case of the trays from Greece and Turkey, most documents mainly talk about their history, their stylistic and iconographic characteristics. They also refer to their possible decoration techniques (Nessi and Hatzaki, 2013) and to printing stamps of well-known factories which were found only on some specially made pieces for the Greek and Ottoman market. For example the emblems of the ducal crown stamp from the Stockmann factory (Righter, 2005: 119). Hence many questions were raised about how these artifacts were made since they were manufactured in the time of the industrial expansion, the widespread trade of raw materials and the participation of different workshops during their manufacture (Jones, 2012).

The present study focuses on the metallurgical features of the metal ware substrate (the painted layer was examined separately), in an effort to receive as much information as possible about these painted ‘japanned’ metal trays. Apart from Helwig’s analysis study of the japanning layer (Helwig, 2001: 27-33), the literature was very limited and the scientific data published, seem to be scant. The work includes the observation and analysis of the trays (substrate, handles and rim), the interpretation of the resulting data and also the searching of their possible origin: Were these trays made in Greece and Turkey where they come from or were they European products manufactured for the Greek and Ottoman market as several scholars refer to?

Undoubtedly the sample of trays for investigation was not as broad as required due to the high cost of the analysis, the time limitations and/or the restricted allocation of more artifacts-samples. Nevertheless, an attempt was made by combining the metallurgical evidence even limited with historical reports on the trays subject and with information linked to the economic history of Greece and Turkey of the 19th century. It is believed that it is a preliminary approach for a further comprehensive study of such or similar artifacts.

**Analytical and sampling methods**

Twelve trays out of the total, on loan from private collections and the Benaki Museum, were grouped in five categories according to some early date assessments by the curators of the exhibition (Table 1). Their grouping was based upon the iconographic themes and the stylistic characteristics of the trays such as their oval or rectangular shape, the shape and decoration of the handles as also the way of their attachment. Their dating also relied on macroscopic assessments of the possible decorative techniques applied to the colored japanned layer.

This relatively small collection was subjected to several analytical techniques: macroscopic and microscopic observation using a Leica Wild M3Z stereoscope. Cross-sectional observation (OM), using an Olympus AX70 appliance under bright field and polarized light where small samples (0.5-1 mm) were extracted from the metal support (15 samples), rim (4 samples) and handles (5 samples) of the trays and embedded in a two-compound epoxy resin (Epofix, Struers). Qualitative and quantitative elemental analysis of an almost cleaned area (about 3 mm in diameter) on the back, handle and rim of each tray, by applying a portable X-ray fluorescence (XRF) spectrometer (Sokaras, et al., 2009: 2199-2209). The quantification was based on the Fundamental Parameter (FP) method by means of in-house (N.C.S.R. ‘Demokritos’) developed software which consists of a low power X-ray tube, a Si- PIN diode X-ray detector and a digital pulse processor PX4. Finally, observation and chemical analysis of seven cross sections from the metal substrate (mainly one selected from each chronological group except D7 and D8 that belong to the same group) using a Jeol JSM-S310 Scanning Electron Microscope (SEM-EDAX). The analysis was carried out on three different extensive areas of the iron matrix and on four to six ones of the entrapped slag inclusions (defined in each sample) for bulk composition in order to reduce the risk of localized concentration effects since the samples and slags were quite small. Spot analysis of separate slag phases was also applied. A total of 2-19 elements were determined depending on the analysis regions. Their average percentage was calculated and compared with analysis results of previous studies. SEM-EDS analysis of the other parts and samples could not be achieved.

**Results**

The macroscopic and microscopic observation of the trays revealed two stylistic types (Table 1). One was manufactured from two pieces of metal (substrate/peripheral metal sheet) and cut-out handles (group A’). The other (groups B’,C’,D’ and E’) was made in one piece (in an oval shape with almost vertical walls or rectangular and more shallow) with separately made handles and a metal ring at the rim utilized either as a support or for decorative purposes (Figure 1a,b). A metal ring was also recognized on tray D2.

In the former case, the two metal parts were connected together with a metallurgical bond in order to construct the shape. Their attachment was achieved...
| Trays            | Iconographic theme                                      | Dating groups                                      | Owner                 | Japan layer | Shape               | Dimentions with handles | Thikness | Handles | Rim                          | Analytical techniques                                      |
|-----------------|---------------------------------------------------------|---------------------------------------------------|-----------------------|-------------|---------------------|-------------------------|----------|---------|-------------------------------|-------------------------------------------------------------|
| D1              | Tavern Science                                         | Group A’ (late 18th-early 19th century)           | Nessi collection      | Blue        | oval                | 40.5 × 51.5cm           | 4.2mm    | Cut-out handles               | XRF analysis, Metallography (wall, base) SEM (base, wall)    |
| D2              | Allegory of Trade                                       | Group A’ (late 18th-early 19th century)           | Lesueur collection    | Ivory       | oval                | 44.5 × 57cm             | 4.1mm    | Cut-out handles               | XRF analysis, Metallography (wall)                           |
| D4              | Sailboats by the coast                                 | Group B’ (mid-19th-late 19th century)             | Eleftheriadi collection| Beige       | Rectangular        | 48 × 64.5xcm            | 4.3mm    | Attached                       | XRF analysis Metallography (wall, rim) SEM (wall)            |
| D5              | Female portrait                                         | Group B’ (mid-19th-late 19th century)             | Nessi collection      | Pink        | Oval                | 41.5 × 52cm             | 4.2mm    | Attached                       | XRF analysis Metallography (wall, rim) SEM (wall)            |
| D6              | Danae and the Rain of gold                             | Group B’ (mid-19th-late 19th century)             | Eleftheriadi collection| Pink        | Rectangular        | 41.5 × 56cm             | 4.3mm    | Attached                       | XRF analysis Metallography (wall, rim) SEM (wall)            |
| D3              | Woman with stylized crown                              | Group C’ (late 19th century)                      | Lesueur collection    | Green       | Oval                | 42 × 53cm               | 4.2mm    | Attached                       | XRF analysis Metallography (wall, rim) SEM (wall)            |
| D9              | A Steam engine puffing smoke surrounded by a ‘frieze’ of Constantinopolitan views ans land marks | Group C’ (late 19th century)                      | Benaki Museum         | Red         | Oval                | 46.2 × 58.3cm           | 4.1mm    | Attached                       | XRF analysis Metallography (wall, base)                      |
| D10             | Woman Spinning                                         | Group C’ (late 19th century)                      | Nessi collection      | Blue        | Oval                | 38 × 49.5cm             | 4.2mm    | Attached                       | XRF analysis Metallography (wall, base, rim, handle)        |
| D13             | Hallmark view of Constantinople and its two bridges (late 19th century) | Group C’ (late 19th century)                      | Nessi collection      | Green       | Rectangular         | 54 × 79cm               | 4.5mm    | Attached                       | XRF analysis Metallography (wall, base, handle) SEM (base)   |
| D11             | Constantinople and the Galata bridge                    | Group D’ (late 19th-century-early 20th)           | Nessi collection      | Red         | Oval                | 47.5 × 59cm             | 4mm      | Attached                       | XRF analysis Metallography (base, handle) SEM (Base)         |
| D7              | Ideal female                                           | Group E’ (early 20th century)                     | Private collection    | Light blue  | Oval                | 38.5 × 47cm             | 4.1mm    | Attached                       | XRF analysis Metallography (wall, base, rim) SEM (Base)      |
| D8              | Constantine and Sophia                                 | Group E’ (early 20th century)                     | Noitakis collection  | Light green  | Oval                | 47 × 59cm               | 4mm      | Attached                       | XRF analysis Metallography (wall, handle) SEM (Base)         |
by means of iron welding, an effective technique where pieces of iron must be white-hot in order to be joined by hammering and to allow for diffusion bonding (Hodges, 1995: 86-87). In the second case, the handles were separately made and attached onto the main body mechanically by properly formed rivets with shaped heads by special snaps, secured by a nut.

Both types presented a ‘protective’ layer over the underlying iron substrate prior to the previously mentioned japanned layer. The earliest trays (D1, D2) were tin plated and in particular hot-tinned as evidence by the corresponding cross section image of D1 (Figure 2). The tin layer revealed the diffusion of tin into iron which had occurred from the immersion of the tray in molten tin. Based on the 86.95% amount of tin analyzed on the surface, diffusion was incomplete due to the fact that no heating was applied afterwards (Meeks, 1993: 247-275).

The rest of the trays revealed a red iron oxide primer (Figure 3). This layer could give either a significant protective function to the iron substrate (Matero, 1994: 197-228) and/or an aesthetic result as a tinting factor (opacifier) for the painting layers (Van Hout, 1998: 238). It could also ensure a perfectly smooth surface to accept the painting layer since it could be well polished as in the case with the ‘bole’ used for

Figure 1. The two characteristic stylistic types of the trays. D1 was made of two pieces of metal and cut out handles while D4 (rectangular in shape) was made in one piece with separately made handles.

Figure 2. SEM image of D1 wall cross-section. Excess tin (86.9%) was detected on the surface indicating incomplete diffusion of the metal.
Byzantine icons from the 9th century AD (Eastauch et al., 2004: 57).

**Substrate**

The substrate manufacture technique was not identifiable either macroscopically or under the stereoscope. The only general macroscopic observation that could indicate a later and more massive metal production was the relatively uniform shape and thickness of the vast majority of the trays (Table 1).

Therefore fifteen samples of the base (D1, D3, D4, D5, D7, D8, D9, D10, D11, D13) and walls (D1, D7, D8, D9, D10) of the trays, were subjected to cross-section examination. The microstructure after etching in natal (2% nitric acid in alcohol), revealed a depressed ferritic grain structure (α-phase) with entrapped slag particles distributed throughout the metal. Slag inclusions were either elongated across the width of the sections (Figure 4) or rounded and globular (Figure 5). The latter were specifically identified on the wall sections. In groups A′, B′ and C′ (except D9), slag inclusions presented several...
sizes (2μm-1.37 mm) and were either multiphased or single phased with a glassy appearance. In some cases (D3,D4,D10), the crystal structure of the larger-sized slags, appeared broken up into small angular fragments. On the contrary the slags from groups D’ and E’ including D9, were smaller and more homogenous in size (695.9nm-25.9μm). Any slag phases could not be distinguished. The same groups, were characterized also by the fewer slags present (Figure 5) illustrating a cleaner iron matrix. D1 also presented a small amount of slag (Figure 6) but its overall picture did not concur with the one observed at the ‘cleaned’ groups.

This type of orientation of both grain and slag is typical of iron metal deformed by the application of ‘forces’. The recognition of a fibrous texture through the grains of most samples except D1 and D13 supported such estimation (Scott 1991: 9). However this ‘texture effect’ was not easily recognized at all the base samples. If it existed, it had been flattened, leaving parallel striations throughout the metal. This meant that the grain structure of the walls was not completely randomly oriented during recrystallization in relation to the base which was worked further. In fact, the base, presented a more distorted grain structure compared to the walls that showed less depressed grains with a limited number of strains (Figure 7). Therefore according to such characteristics and in accordance with the style of these particular artifacts made in one piece, it was implied that a different kind and more efficient force was applied than the iron forging hammer.

Figure 5. D7 wall cross-section: Uniform grains and a cleaner iron matrix due to the few and small slag inclusions (100x). The fibrous morphology across the width of the section can also be observed.

Figure 6. D1 wall cross-section, which shows great variability in ferritic grain size and few multiphased slag inclusions (150x).
The use of different and even more sophisticated equipments was also indicated by the relatively uniform grain size (85-150 μm, Figure 4,5,7) these samples bore. D1 (handle/walls) and D13 (Figure 6) were exceptions again, as their grain structure displayed greater variability (20-140 μm).

Therefore due to the homogenously reduced thickness of the metal, the fibrous texture similar to the one left by the application of the rolling mill and also the breakup of the slag present (Tregoning, 1901: 1273-1282), it was suggested that the rolling mill, a method known since 1697 for tin-plate (Jones, 2013: 133-147), was the initial manufacturing technique of the sheet iron. In addition, according to the differences between the base and wall as also to the trays uniform shape and metal thickness observed macroscopically, drop hammers and screw- or hydraulic presses combined with die forms were indicated, giving to the trays their final shape; more clear for D8/D9/D11 or D3/D5 due to their almost absolute matching in size and thickness. The rest, probably belong to other massive groups with similar dimensions which were not available in our study. The sample extracted from tray D1 seemed more likely to be the result of forging (Hodges, 1995: 86-87) and in particular of high quality forging work which squeeze out but never eliminate the slag (Scott 1991: 102; Craddock, 2003: 231-238). The one received from D13 could indicate the operation of a power forging hammer with particular dies since the overall shape and thickness of the tray, support a more massive production.

The carbon content for most samples was low and explained by the limited concentration of pearlite (α + Fe3C) at the boundaries. On the contrary the pearlitic regions of the sections belonging to Groups D’ and E’ appeared slightly more extensive. Such image indicated a little higher concentration of carbon in the iron metal (Figure 8) as iron can dissolve a certain extent of carbon (Scott, 2017: 6). The extra amount precipitated as a second phase.

Therefore the main metal used for the trays fabrication was wrought iron or, more precisely, low carbon steel (Hodges, 1995: 80). Wrought iron was also confirmed by XRF analysis along with various other elements which were attributed to the japan ground, painted layer or dryers (Table 2). The carbon content was estimated at approximately 0.5% or less.

Wrought iron could be either produced from the solid-state bloom process (direct reduction) or indirectly by re-melting cast iron in an oxidizing atmosphere, known as fining, a method posterior to bloomery smelting which is used until today (Craddock, 2009:153). Unfortunately, the optical distinction of wrought iron made by the two different operations was difficult since both smelting procedures leave slag inclusions in wrought iron. These either remain after the direct reduction or created after the indirect during fining (Craddock, 2009: 153; Buchwald and Wivel, 1998: 73-96). Some slag inclusions could even be related to the forming processes applied. Even though some are lost, new ones are created and remain in wrought iron (Dillmann and L’Héritier, 2007: 1810-1823; Blakelock et al, 2009: 1745-1757).

The evaluation of the smelting process involved, was based on the composition analysis of the slag inclusions by SEM (Table 3). SEM confirmed the two main slag types microscopically distinguished in samples D1, D5 and D13. A few, were totally glassy but most of them were a wustite(FeO)-fayalite(Fe2SiO4)-glass composite together with other elements including sulphur. Alternatively, slag of D7, D8 and D11, were mainly wüstite which contained the same elements as mentioned above but with higher amounts of Manganese and Sulphur. In D7, lead, zinc, tin and copper were also detected.
Figure 8. D11 body cross-section. Ferritic grain structure containing a few slag inclusions and slight extensive pearlitic regions concentrated at the boundaries (polarized illumination, 200x).

Table 2. XRF semi-quantitative analysis results of the substrate. The non-quantified elements (nq) are attributed to exogenous factors. The asterisk relates to those analysis and nq elements which are attributed to the Japan ground, painted layer or dryers. The elements in bold, are probably connected to both the decorative layer and/or metal. MDL for Mn and Ni are 50 ppm.

| Trays | Elements% | Fe | Pb | Zn | P | S | Cl | K | Ca | Ba | Cr | Mn | Cu | As | Si | Sr | Hg |
|-------|-----------|----|----|----|---|---|----|---|----|----|----|----|----|----|----|----|----|
| D1    | >99.4     | *0.1 | -  | -  | - | - | -  | - | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| D2    | >99.8     | *0.2 | *0.2 | nq | - | - | -  | - | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| D4    | >99.5     | *0.4 | -  | -  | - | 0.5 | nq | nq | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| D5    | >99.0     | *0.4 | *0.1 | - | - | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| D6    | >99.8     | *1.4 | -  | -  | - | -  | -  | 0.6 | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| D7    | >99.4     | *0.5 | -  | -  | - | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| D9    | >99.6     | *0.1 | -  | -  | - | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| D10   | >99.0     | -  | -  | -  | - | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| D13   | >88.0     | *4.5 | -  | nq | nq | nq | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| D1    | Base/Wall | Iron matrix | - | - | 0.1 | - | - | - | - | - | - | - | - | - | - | - | - | 98.3 | - | - | - | - |
| D1    | Slag      | 0.2 | 0.6 | 1.0 | 13.0 | 3.0 | 1.0 | 0.2 | 0.1 | 1.0 | 0.2 | 0.1 | 0.2 | 0.2 | 11.8 | 62.1 | - | - | - | - |
| D5    | Wall      | Iron matrix | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 96.1 | - | - | - | - |
| D5    | Slag      | 0.4 | 1.1 | 3.6 | 10.6 | 0.8 | 0.7 | 0.1 | 0.7 | 5.0 | 0.2 | 0.4 | 0.1 | 0.1 | 3.3 | 52.2 | - | - | - | - |
| D7    | Base      | Iron matrix | 0.2 | 0.3 | 0.3 | 0.5 | - | 0.6 | 0.2 | 0.1 | - | 0.5 | 0.5 | - | - | - | - | 92.4 | - | - | - | - |
| D8    | Base      | Slag | 0.4 | 0.2 | 0.4 | 14.7 | 1.2 | 1.2 | 0.1 | 0.1 | 0.3 | 0.7 | 0.1 | 0.2 | 0.3 | 19.5 | 44.5 | 0.6 | 0.2 | 1.6 | - | - | - |
| D8    | Iron matrix | 0.3 | 0.4 | 0.5 | 0.4 | - | 0.6 | 0.5 | 0.1 | 1.0 | - | - | - | - | - | 0.6 | 96.6 | - | - | - | - | - | - |
| D11   | Base      | Slag | 0.4 | 0.4 | 0.5 | 30.1 | - | 6.8 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.2 | 12.6 | 43.4 | - | - | - | - | - | - |
| D11   | Iron matrix | 0.3 | 0.4 | 0.3 | 0.4 | 0.3 | 0.5 | 0.2 | - | 0.2 | - | - | - | - | - | 0.6 | 97.7 | - | - | - | - | - | - |
| D13   | Base      | Slag | 0.4 | 0.5 | 0.5 | 0.8 | 0.7 | 2.4 | 0.2 | 0.1 | 0.3 | - | 0.2 | 0.2 | 0.2 | 29.2 | 50.0 | - | - | - | - | - | - |
| D13   | Iron matrix | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 88.6 | - | - | - | - |

Table 3. Normalized average SEM-EDS analysis data of the iron matrix and slag inclusions of samples D1 (base/wall), D5, D7, D8, D11 and D13.

| Trays | Elements% | Na | Mg | Al | Si | P | S | Cl | K | Ca | Ba | Ti | V | Cr | Mn | Fe | Cu | Zn | Pb |
|-------|-----------|----|----|----|---|---|---|----|---|----|----|----|---|----|----|----|----|----|----|----|
| D1    | Base/Wall | Iron matrix | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 98.3 | - | - | - | - |
| D1    | Slag      | 0.4 | 1.1 | 3.6 | 10.6 | 0.8 | 0.7 | 0.1 | 0.7 | 5.0 | 0.2 | 0.4 | 0.1 | 0.1 | 3.3 | 52.2 | - | - | - | - |
| D5    | Wall      | Iron matrix | 0.4 | 0.2 | 0.4 | 14.7 | 1.2 | 1.2 | 0.1 | 0.1 | 0.3 | 0.7 | 0.1 | 0.2 | 0.3 | 19.5 | 44.5 | 0.6 | 0.2 | 1.6 | - | - | - |
| D7    | Base      | Iron matrix | 0.3 | 0.4 | 0.5 | 0.4 | - | 0.6 | 0.5 | 0.1 | 1.0 | - | - | - | - | 0.6 | 96.6 | - | - | - | - | - | - |
| D8    | Base      | Slag | 0.4 | 0.5 | 0.5 | 30.1 | - | 6.8 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.2 | 12.6 | 43.4 | - | - | - | - | - | - |
| D11   | Base      | Slag | 0.4 | 0.4 | 0.5 | 0.8 | 0.7 | 2.4 | 0.2 | 0.1 | 0.3 | - | 0.2 | 0.2 | 0.2 | 29.2 | 50.0 | - | - | - | - | - | - |
| D13   | Base      | Slag | 0.4 | 0.5 | 0.5 | 0.8 | 0.7 | 2.4 | 0.2 | 0.1 | 0.3 | - | 0.2 | 0.2 | 0.2 | 29.2 | 50.0 | - | - | - | - | - | - |

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From the various elements analyzed (expressed in oxides), MgO, K₂O and Al₂O₃ indicated the smelting procedure used. These compounds are not reduced (NRCs) whatever the operation is and constitute the signature of the smelting process by giving high or low values (L'Héritier et al. 2013: 409-420). In Figure 9 this relation can be seen for all trays and since their amounts were low, they fell in the indirect process area (Dillmann and L'Héritier, 2007: 1810-1823; Buchwald and Wivel, 1998: 73-96). In fact these quantities were almost eliminated and since sulfur was also identified, the more improved indirect process (puddling) was suggested (Buchwald and Wivel, 1998: 73-96). Only D13 showed a slightly increased percentage of Al₂O₃ but it was more probably relative to the exploitation of aluminum-rich ores.

Sulphur in particular, implied the use of fossil fuels therefore the indirect smelting (King, 2002: 43-53). These minerals were a common practice in China since the first millennium AD (Craddock 2003: 231-258) but in Europe (England, Sweden, later in Russia) were utilized (converted coal to coke) from the 18th century (Craddock 2009: 154), replacing charcoal since the shortage of wood for making charcoal had restricted the expansion of iron production (King, 2005: 1-33; Zablotski, 2003: 173-179). The sulphur contents for all trays except D13 were high (0.7-6.8%). Such percentages according to Buchwald and Wivel analysis (1998: 73-96), did not only indicated fining but also the improved indirect smelting process (puddling). In D13, sulphur was quite small which could suggest that the ferrous metal used for this tray was obtained from smelting in the blast furnace with charcoal.

The indirect procedure was also addressed due to the high amounts of FeO (>43.4%) (Dillmann and L'Héritier, 2007: 1810-1823; Buchwald and Wivel, 1998: 73-96) even though this compound is not known for its stability during the smelting and fining operations; almost completely reduced to cast iron but re-oxidizes and reacts with other elements during fining (Blakelock et al, 2009: 1745-1757).

Similarly SiO₂, low percentages (<30%) in general, were adapted to the indirect process (Dillmann and L'Héritier, 2007: 1810-1823; Buchwald and Wivel, 1998: 73-96) although this compound could have been influenced by several factors. These were either relative to the small size of inclusions or to smelting and post-smelting operations (Dillmann and L'Héritier, 2007: 1810-1823). According to Figure 10, silica seems to be affected in the SIs of samples D1, D7 and D8. In all cases a localized influence may be considered, probably coming from the use of coke fuel which consists of high silica (Selwyn, 2004: 90), thus explaining the marginalization of D13 for which charcoal as a fuel has been suggested. D1 was more probably influenced from the sand or clay flux incorporated during forging (Dillmann and L'Héritier, 2007: 1810-1823; Charlton et al, 2012: 2280-1293). This suggestion was not taken into account for the other slags since no forging was implemented.

Other compounds which were used as indicators of fined iron were V₂O₅, Cr₂O₃ and BaO in spite they do not belong to the basic oxides (Buchwald and Wivel, 1998: 73-96). The two former, were found in the wustite phase of the slags in quantities over 0.3% and 0.2% respectively together with manganese and aluminum. The BaO, a compound also related to the direct operation was identified in negligible amounts which are evident of its consuming by the blast furnace (Buchwald and Wivel, 1998:73-96).

**Figure 9.** Ternary diagram showing the chemical relation between Mg-Al-K in the iron oxide slag system of all trays. D13 shows an increased percentage of Al.

**Figure 10.** Scatter plot of Al₂O₃ versus SiO₂ based on Dillmann and L'Héritier (2007:1810-1823) scatter plots (Fig.7) presenting the different contents of SiO₂ in SIs influenced either from sand additives during forging or from the smelting stage. In the case of the trays, the high SiO₂ amounts observed at D1, D7 and D8 probably came from a localized effect. At D1, this amount may have been also influenced from the sand or clay flux incorporated during forging. The SiO₂ contents of slags D5 and D11 were constant, probably coming from the smelting operation. D13 seems to be unrelated to the rest.
On the contrary CaO, also a NRC, could not be used as an element of discrimination since lime may have been introduced as a flux either in the blast furnace or in the fining process (Dillmann and L’Héritier, 2007: 1810-1823). Respectively P2O5 could not indicate the indirect process with certainty. Since it was a changing compound during the smelting operations it was relevant either to the ore (Buchwald and Wivel, 1998: 73-96) or to the fuel used (L’Héritier et al, 2013: 409-420). In this case according to its amounts (< 3.4%), the fuel was suggested (L’Héritier et al, 2013: 409-420) which it could be either charcoal (Charlton et al, 2012: 2280-1293) or fossil (Tylecote, 1991: 200-260).

Finally MnO a major compound in all slag as well, was either ore related or an indicator of improved iron smelting production methods (Figure 11). Specifically, in slags of samples D5 and D13, manganese was encountered in low or very low quantities (3.3 and 2.0% respectively). These amounts pointed out to its use as a flux in the smelting practice (Buchwald and Wivel, 1998: 73-96) and thus according to the data discussed above to the indirect process. Manganese detected by XRF in D3 and D6 could also be included in this case.

In slags of D1, D7, D8 and D11, a higher concentration of manganese was present. For D1 probably a manganese-rich ore was used (L’Héritier et al, 2013: 409-420). For the rest, since Mn was even detected in the iron matrix of the slags and had also a noticeable appearance analyzed by XRF (Craddock, 2009: 154), it was conjectured that a ‘carburet of manganese’ (Mn in the metallic state) must had been introduced (Gutzmer & Beukes, 2009: 43-69), in a much hotter and more reducing atmosphere analyzed by XRF (Craddock, 2009: 154), indicative of casting. Indeed, the two only samples that could have been extracted (from trays D10, D13), when etched in alcoholic ferric chloride, showed coarse dendrites of the α-phase with complete solid solubility of a second major metal together with a few pores. This microstructure configuration clearly characterizes a metal that had been cast to shape (Scott, 1991: 113) which according to XRF analysis was an alloy made of copper and tin (Table 4). In addition, some interdendritic regions were filled by very small globules, (black under bright light and grey under polarized), similar to lead phases (lead was confirmed by XRF) and in D13 by the limited α+δ eutectoid phase, probably of tin (Scott, 1991: 25) which was the last to freeze (Figure 12). Tin was indirectly ‘confirmed’ by XRF analysis.

Consistently the samples indicated slow cooling which, in respect to the properties of the different mold materials known in the literature such as stone (Craddock et al, 1997: 1-9), clay (Hodges, 1989: 70-73) or sand (La Niece, 2003: 90-96) and the thermal processes conducted in these moulds (Kotzamani, et al., 2011), could suggest sand casting, a technique known since the 11th century AD (La Niece, 2003: 90-96). Sand is characterized for its slow cooling rates compared to the other materials (Eccleston and Ottaway, 2002: 185-189; Balasubramaniam and Jeyaraj, 1997: 200-205) but it should be taken into consideration, that slow cooling can be ensured also for the other mold materials with deliberate operations (Shriniwasan and Glover 2007: 35-40; Mandall and Datta 2010: 171- 177; Tylecote, 1992: 39). These balance the temperature between the mold and the hot metal

**Figure 11.** Principal component score plot of the % concentrations of Mg, Al, K, Mn, based on their average SEM-EDS analysis results in the Sls. Three subgroups can be seen: a) with a very low Mn amount (D13) b) with a low Mn amount (D5) and c) with a high Mn amount (D1, D7, D8, D11).
thus any uncontrollable flow that will cause impregnation of the mold is avoided. Nevertheless, it is believed that the simple shape of the handles and the period of manufacture, also advocated the use of the particular fabrication technique even if the seam line which is initially left by the use of the two-piece molds (Untracht, 1975: 325-326), was unidentifiable. This looked as the result of grinding and polishing that followed. Indeed, abrasive scratches could be observed on the metal surface.

Brass according to XRF analysis did not only contain lead and tin (in some trays) but also small amounts of iron and/or nickel. The zinc content ranged from 22 to 29%. Such percentages could have been reached either by the ordinary but improved cementation process with careful regulation of the temperature in lower levels or succeeded by the more modern speltering process (Craddock, 2009: 148). In the first case, a finely divided or granulated copper was heated together with a calcined zinc ore (zinc oxide) and charcoal in a closed crucible (Craddock, 1995: 297). During the second method, copper was mixed with zinc in its metallic form.

The distinction between the two methods on the basis of such metal composition was difficult (Craddock and Eckstein, 2003: 216-230). The cementation procedure could be considered as dominant due to the iron detected in four handles (D3, D4, D5 and D11) in accordance with the purity of brass since minor elements such as cobalt, arsenic, antimony, silver and bismuth, known to be especially connected with copper/copper ores were absent (Craddock, 2009: 141). A more rigorous refining of copper was suggested as this operation was improved during the 19th century (Craddock, 2009: 139). The ferruginous inclusions in this case, seem to be related to zinc as contaminants

**Table 4.** XRF quantitative analysis results of the attached handles of groups B’ and C’ together with semi-quantitative analysis results of the handles of groups D’ and E’. The non-quantified elements (nq) are attributed to exogenous factors. The asterisk relates to those nq elements which are attributed to the painted layer. The elements in bold, are probably connected to both the painted layer and/or metal.

| Trays | Fe  | Pb  | Zn  | S   | Cl  | K    | Ca  | Sn  | Ba  | Mn  | Cu  | As  | Si  | Ni  |
|-------|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|
| D1    |    |    |     |     |     |      |     |     |     |     |     |     |     |     |
| D2    |    |    |     |     |     |      |     |     |     |     |     |     |     |     |
| D4    | 0.6 | 0.4 | 25.0 |     | nq  | nq   |     |     |     |     |     |     |     |     |
| D5    | 0.2 | 0.7 | 29.0 | nq  | nq  | nq   | 0.3 |     |     |     |     |     |     |     |
| D6    |    |    | 22.0 |     |     |      | 0.6 | 0.4 |     |     |     |     |     |     |
| D3    | 0.5 | 0.3 | 23.0 | nq  | nq  | nq   |     |     |     |     |     |     |     |     |
| D9    |    |    | 29.0 | nq  |     |      |     | nq  |     |     |     |     |     |     |
| D10   | 0.4 | 2.0 | 23.0 |     | nq  |      |     |     |     |     |     |     |     |     |
| D13   |    | 1.5 | 27.0 | nq  | nq  | nq   | 1.5 |     |     |     |     |     |     |     |
| D11   | >71.0 | 0.3 | *2.0 |     | nq  |      | 28.0 |     |     |     |     |     |     |     |
| D7    | >74.0 | 18.0 | *0.1 |     |     |      | 8.0 |     | 0.1 | *0.2 |     |     |     |     |
| D8    | >95.0 | 0.1 | *0.2 | nq  |     |      | 4.0 |     | *nq| 0.2 | *0.2 |     |     |     |

**Figure 12.** Cross-section of D13 handle made of brass. Coarse dendrites of solid copper α-phase with complete solid solubility of zinc, filled by very small lead phases (black) and by the α+δ eutectoid phase probably tin which was the last to freeze (200x). Light blue-grey inclusions are attributed to sulphur.
from the zinc ores, a problem which could not be avoided with the cementation procedure (Craddock and Eckstein, 2003: 216-230). Especially though when oxidised carbonate ores (smithsonite \( \text{ZnCO}_3 \)) where used (Craddock, 1995: 298). However their contents were low (0.1-0.9%) compared to the ones detected at some contemporary European brasses (0.1%-2%) reported by Craddock et al (1990: 73-101). Thus the use of more sophisticated methods of production could be supported (Craddock et al, 1990: 93-101).

Alternatively, where iron was not detected (D6,D9, D13), both processes were proposed. Either the cementation, if sulphide ores (sphalerite \( \text{ZnS} \)) had been used (Craddock and Eckstein, 2003: 216-230) or speltering since distilled zinc produced from carbonates was added (in the first efforts of zinc metal production in Europe. Almond, 1998: 216-230). The microscopic recognition of sulphur in the cross section of D13 indicated the primer operation, and the exploitation of sulphide ores which were well known in the east in relation to the west (Craddock et al 1990: 93-101) unless brass was made in Europe. In this case sulphide ores were probably imported from the east, a common practise known since the 16th century (Craddock and Eckstein, 2003: 216-230). Unfortunately such observation could not be confirmed, as no chemical analysis took place at the sample.

Speltering could have been implemented for D6 and D9 but not with certainty. This possibility coincides with reports about the use of zinc metal produced from smithsonite ores available in Europe and the demise of the cementation process until after the mid-19th Century (Almond, 1998: 159-229).

Unfortunately lead as a major impurity in almost all handles (0.3-0.9% for D3,D4,D5,D6,D9) was not an ancillary one in this distinction. Lead was either associated with the zinc or with the copper ores (Oddy et al, 1986: 9). It could have been also connected with the smelting of the copper ores used as a flux or the liquation of copper ores containing silver, a procedure known at various times and locations in Classical Antiquity and Japan or Europe since the Medieval period (Craddock, 2009: 140).

Even the other two major impurities tin (D4,D6, D13) and/or nickel (D5,D3,D9,D10) could not be of some significance in this distinction. Tin (0.3-1.5%) was more probably reflected the introduction of scrap metal (probably copper) as was demonstrated from previous studies (Oddy and Craddock, 1983: 753-57; Day, 1990: 123-149). In fact the positive variation of tin and lead in Figure 13 for the three samples and also their low amounts, appear to confirm that these metals were connected from the past. As regards nickel (0.1-0.3%), it was also an element connected with the copper ores and even an indication of specific sources (Craddock 2009: 142 with reference to Scott and Pondanzy 1990 or Riederer, 1981, 87, 88, 99a).

Perhaps, the most important proof of the use of cementation was the absence of cadmium combined with the low amounts of iron and the higher contents of zinc. Cadmium which frequently existed in the zinc ores was too volatile to remain after the completion of this procedure, thus it was lost (Craddock and Eckstein, 2003: 216-230). On the contrary it usually remained after speltering even in very small amounts.

The rest of the elements such as sulphur, silicone, lime, chloride and potassium, detected in the copper alloy of trays D3, D4 and D13 by XRF, were attributed to the atmospheric environmental conditions (Selwyn, 2004: 62-64; Scott, 2002: 227-132) and/or to recent cleaning treatments with products that affected the surface of the handles (Selwyn and Costain, 1992: 3-16). However sulphur in D3 could be related to the exploitation of zinc sulphide ores as was conjectured above for D13 but more analysis is required.

The handles made of iron (groups D' and E'), looked as forged. According to the metallographic images of D7 and D11, their microstructure was similar to the cross-sections obtained from the wall and base of the relevant trays. The main difference observed, was the shape of the grains (Figure 14) left in a re-crystallized condition and size (20µm-100µm depending on the object).

The whitish metal discovered on their surface and analysed by XRF, revealed either tin or a tin/lead alloy (terne), similar to tinplate. The second type of alloy containing at least 5% tin was used since around 1720 (in Wales, as demonstrated by Selwyn, 2004: 100). It was often applied over iron in the form of a coating either for decoration or protection as a sealer (Brown, 1988: 42-48) and was also a cheap substitute for silver. Electrolytic deposition of this alloy on iron was suggested in relation to the more traditional hot-dip or wipe-tinning plating techniques, but further
Investigation is needed. The zinc and copper detected by XRF, were attributed to metallic pastes applied to the plated surfaces. These were probably more recent innovations since the tin was found to be lost from several areas.

**Ring**

Examination of the trays rim under the stereoscope, showed that the supportive ring was a hidden metal rod made of iron, as identified by XRF (Table 5), over which the raised up sides of the iron substrate were rolled. At these trays the rim had been covered with metallic pigments, confirmed as brass (61.3% Cu and 14.4% Zn) paste by SEM, on a sample obtained from the colored layer of tray D8.

On the contrary, the decorative ring was a hammered sheet attached on the rim of the iron substrate. According to XRF analysis, this ornamented feature was made either from silver plated copper (groups B’ and C’) or brass (D2, D9). Indeed, cross-section examination of the samples extracted from D3, D5, D10 and D13, showed a copper structure with a well formed recrystallized grain matrix and straight twin lines characteristic of successive working and annealing cycles (Figure 15). The grains were finer and flattened only near the edges associated with the bending of the ring in order to be secured onto the edge of the tray. Some light parallel lines observed through the grains of samples D5, D10 and D13 could be attributed to traces left from the rolling mill (if this was the initial technique used for the copper sheet before its placement and attachment) but not conclusively. If they existed, they did not seem to have been maintained as long as additional stages of hammering and annealing had followed (Scott 1991: 8-9).

Silver plating in these sections was recognized as an extremely thin and fragile layer (less than 0.005 mm) with no distinguishing structure and with inconsistency of its thickness (in one case a small area showed

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**Figure 14. Cross-section of D7 handle made of iron. Grains of smaller size and remnants of tin at the surface (200x).**

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**Table 5.** XRF semi-quantitative analysis results of the rim. The non-quantified elements (nq) are attributed to exogenous factors. The asterisk relates to those elements and nq elements which are attributed to the japan ground, painted layer or dryers. The elements in bold, are probably connected to both the decorative layer and/or metal. MDL for Mn and Ni are 50 ppm.

| Trays | Fe  | Pb  | Zn  | S   | Cl  | K   | Ca  | Sn  | Ba  | Cr  | Mn  | Cu  | As  | Si  | Sr  | Ni  | Ag  | Al  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| D1    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| D2    | 94.0 | 0.1 | 4.0 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| D4    | 0.8 | 0.3 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| D5    | nq  | 0.1 |     |     |     |     |     |     |     |     |     | 99.0 |     |     |     |     |     |     |
| D6    |     | 1.0 |     |     |     |     |     |     |     |     |     | 98.0 |     |     |     |     |     |     |
| D3    |     | 0.3 |     |     |     |     |     |     |     |     |     | 99.3 | *0.2 |     |     |     |     |     |
| D9    |     | 0.5 | 32.0 | nq |     |     |     |     |     |     |     |     |     | 67.0 |     |     |     |     |     |
| D10   |     | 3.0 | *25.0 |     |     |     |     |     |     |     |     |     |     | 70.0 |     |     |     |     |     |
| D13   |     | 2.0 | *13.0 | 10.3 | nq | nq | 0.6 | nq |     |     |     |     | 61.0 | *20.0 | nq |     |     |     |     |
| D11   |     | 2.0 | *96.0 |     |     |     |     |     |     |     |     |     |     |     |     |     | *0.1 |     |     |
| D7    |     | 25.0 | *0.6 | *70.0 |     |     |     | nq |     |     |     |     |     |     |     |     |     |     |     |
| D8    | 44.0 | 2.4 | *13.0 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
about 0.011 mm). It also presented poor adhesion to the copper substrate since there was no evidence of diffusion from heating or of mercury application according to the XRF analysis. Such characteristics supported more the 'electrochemical' silvering technique in relation to electroplating with an unknown date of implementation (La Niece, 1993: 211-222). However it was suited to mass production (Oddy, 2000: 1-20).

In addition, the few small inclusions recognized in blue-gray, some flattened out along the length of the samples, were attributed to sulphide impurities (Scott 1991: 101). However, further analysis of the bulk is needed for interpretation. Sulphur could have been related to its containing compounds from the atmospheric environment as chlorides (Selwyn, 2004: 62-64; Scott, 2002: 227/132). Other minor constituents such as lime and/or silica analyzed also by XRF, were more likely connected with the application of cleaning products used in the past for silver polishing (Selwyn and Costain, 1992: 3-16). Nickel seems to be connected with the copper ores as mentioned above.

As regards the brass ring, it was also a hammered product due to its small thickness and the discreet presence of curvatures and irregularities (observation under the stereoscope). Its choice and the way of forming proved for once more that this alloy was deliberately selected, as usual was from antiquity, for its color as a substitute for gold and/or for its decorative and working properties (Bayley, 1990: 7-28).

**Conclusion**

All trays belong to the same category of household goods manufactured from iron, generally referred to as 'wrought iron'. Traditional iron working (forging) in which the metal was shaped by hammering was estimated for group A' thus confirming the curators dating. More modern manufacturing methods such as rolling, followed by die forming processes using screw- and hydraulic-presses, extensively used in Europe from the 17th century and widespread by the 19th century (Webb, 2000: 1-21) were applied to the others except D13 which probably resulted from drop hammers combined with dies.

Group A' also differs from the rest, concerning the 'protective' layer prior to the japanned one. It revealed tin plating over the ferrous substrate while the rest bore an iron oxide primer. This layer was probably used to replace the tin coating as its supply from the early 19th century became difficult (Gerard, 2000: 21). It seemed to provide protection to the iron substrate, good technological properties and less production cost.

Wrought iron in all trays was produced indirectly from cast iron by refining. Iron was smelted with fossil fuels a critical factor in the 19th century, which not only sustained iron production but also lowered cost and improved the smelting technology (Rosen, 2012: 149). D13 seems to be more connected with charcoal which was still in use to a limited degree into the 20th century (Craddock 2009: 154).

On the most recent trays (groups D' and E'), iron looked almost free of slag particles thus pointing out the use of even more effective refining methods (Ettmayer, 1984: 166-174) which were more efficient from the mid-1800 (Postan & Habakkuk, 2008: 447). D9 from group C' was found to be also included in this category therefore its date could be transferred to the late 19th-early 20th century. On the contrary

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**Figure 15.** Cross-section from D3 copper rim: Well-formed re-crystallized copper grains and straight twin lines due to working and annealing. Extremely thin plating layer with poor adhesion (200x). The metal used was detected by XRF as silver.
the slag cleanness of D1, can be explained by high quality forged work. Groups D’ and E’, also revealed the deliberate incorporation of manganese metal for its deoxidizing and desulfurizing properties in order to face up the difficulties which arose from the use of fossil fuels. D7 showed that cast iron was also alloyed in order to improve its resistance to wear, corrosion and heat.

As for the other metal parts (except group A’) and ornamental features of most trays (including D2), the attached handles of groups B’ and C’ were cast and made of brass, a prevalent alloy well known since the 1st millennium AD (Hook and Graddock, 1996: 142-163). The rest (group D’ and E’) were made of iron, formed by forging with more modern equipment and plated with a tin or tin/lead alloy which was also connected to the more recent plating techniques. Brass underwent slow cooling rates thereby indicating the use of the sand molds which were suitable for mass production. The true cementation process was suggested with caution for its production instead of speltering, although both processes existed side by side at the time of the trays manufacture, during the 19th century (Almond, 1998: 159-229). Unfortunately more analysis is needed.

Finally, the metal ring at the rim was decorative (D2 and groups B’ and C’) or supportive (groups D’ and E’, hidden under the rim). The first ones were either made of silver plated copper or brass. The metal sheet was produced by hammering and annealing. Rolling was suggested as the initial forming technique of the sheet metal as in the case with the iron substrate but such hypothesis could not be confirmed. ‘Electrochemical’ silvering seems to be the plating technique used in relation to electroplating even though both were developed in the same chronological period about the first half of the 19th century (Oddy 2000: 1-20). As regards the supportive rings, they were made of a forged iron rod. In this case the rim was covered with metallic colors imitating precious metals probably with the aim of reducing costs.

Iron production in the newly established Greek state and the Ottoman Empire was based upon the sociopolitical and economic factors that prevailed during the 19th century in Europe due to the industrial revolution and the need of an increased supply of minerals (Lepeitit, 1998: 97-116; Diniakos, 1999: 47-48). Therefore several iron exploitation centers had been addressed from the 2nd half of the 19th up to the begging of the 20th century (Agrianthi, 1998: 394-421; Quataert, 1983: 41-69; Günhan Danışman, 2007: 91-110) and either foreign capitals were penetrated (Quataert, 1983: 41-69) and/or expatriate capitals were placed. However the metallurgical activity in Greece and Turkey was characterized by the mining and exportation of raw ores (Chastagnaret, 2000: 872-873; Kokkinakis, 1999; Quataert & Duman, 2001: 153-179). Any investments on facilities, exploitation, new equipment or processes were limited although some industrial iron production attempts had been made (the case of Kimi in Eboea island but unfortunately failed Agriantoni, 1998: 394-421). It is not by chance that several documents refer only to bloomery findings, blast furnaces and water power forging hammers (Özbal, 2008: 65) while there is no evidence on iron purification and the use of fossil fuels in local iron production (Quataert & Duman, 2001: 153-179). There is also limited information on modern applications for fabrication and decoration with particular reference only to a copper sheet rolling mill used in 1826 by Beinin (2001: 40).

So, it could be assumed, that the trays were originally produced in European industries and workshops even if the supply of materials may have depended on different sources either Europe or the East. The same conclusion was realized for the copper/copper alloys as well as for the fabrication of handles which were widely used in Europe (Guéné, 2013: 165-201). For example, the famous zinc carbonate ores of Europe (Craddock et al, 1990: 78) or the new copper sources in Europe which became prevalent due to the low nickel amounts (Craddock, 2009: 142) or the zinc sulphide ores/metal coming from the east (Craddock et al, 1990: 93-101). Even scrap metal was utilized for less cost purposes.

The only exceptions to this assumption were the discovery of the iron oxides primer and the traditional hammering and annealing of the copper ring regardless of whether rolling was used or not. These techniques could have been applied locally even though there are no reports on the in-situ japanning preparation. Indeed most texts (Guéné, 2013: 165-201) refer only to local painting and painting by artists who had considerable contact with the Europeans and exchanged information.

Therefore the trays would have been either painted at the specialized workshops in the European territories as demonstrated by several scholars and in particular for
the earlier made trays with a western iconography (Jones 2012) or exported blank to Greece and Turkey in order to be painted there and perhaps to receive the metal decoration of the rim. The only tray that appears to be different from the rest is D13 supporting not only a different workshop but perhaps a different origin.

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