Technical Studies of Chinese Lacquer


ERRATA: Figures 8 (page 169) and 38 (page 173) as well as figures 22 (page 171) and 30 (page 172) should be transposed!

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The title for this article has been chosen both to recall and to extend the work of Sir Harry Garner which was published almost twenty-five years ago. Garner, a collector of Far Eastern art, was the author of several pioneering publications, particularly on Oriental lacquer. He was the first person in the West to employ scientific techniques to try to explain the technical and technological peculiarities of Oriental lacquer. He combined a scientific approach, resulting from his education as a mathematician and astronomer, with a knowledge of Far Eastern art, evidenced both in his publications and by the works of art he donated to the British Museum and to the Victoria and Albert Museum in London. His interdisciplinary interests can be seen in his "Technical studies of Oriental lacquer," published in 1963. He pursued these interests until his death in 1977 and they are found again in the second chapter of his book Chinese Lacquer that appeared posthumously in 1979 and that also deals with the technological aspects of urushi.

The beginnings of the present article go back to 1976 and my first thoughts were based on Garner's preliminary work (1963). The aim of these investigations was to find out to what extent scientific examination could help to answer questions of dating, provenance, or identification of Chinese lacquerware. At the same time I intended to extend Garner's work, which concentrates on two pieces from the Ming dynasty (1368–1644), by introducing a series of additional objects to cover a greater timespan, i.e. from Zhou (1027–256 B.C.) to Qing (1644–1912). These investigations and their results are the subject of this article.

Garner's literary estate

It was a happy coincidence that, while a member of the Urushi Study Group in Japan in 1985, I learned that Garner's literary estate was in the possession of the Victoria and Albert Museum in London. Thanks to the generous cooperation of that museum, I was able to study the papers while preparing this article. Garner's papers confirmed that he had tried repeatedly with the help of the natural sciences to solve the technical questions which had occupied him greatly, in and beyond his publications of 1963 and 1979.

At the start of his work there are written notes of his visual appraisal of lacquer objects mainly carved from the sixteenth to eighteenth centuries. The first concrete analytical results soon arrived and are included in Table I of his publication of 1963. They cover not only qualitative but also quantitative emission spectral analyses. Unfortunately, it was difficult to isolate a layer for emission spectroanalysis and so it was necessary to repeat some of the measurements.
At the end of 1962 Garner received five fabric analyses that, together with the cross section and the analyses already mentioned, provided the data for his publication of 1963. This work was received with interest and goodwill. In the same year R.J. Gettens gave Garner additional experimental advice on a piece of carved lacquerware from the late sixteenth century. He recommended the use of a "microscope with vertical illuminator and dark field stop" and magnification of 100-200x. It is interesting that one of the dark layers in this investigation was described as "transparent and non-pigmented." This observation will be discussed later. In reference to the same cross section, A.R. Sollars informed Garner that he had followed the usual procedures for preparing cross sections for microscopy and photomicrographs and that he agreed in general with Gettens' findings. One of the photomicrographs he sent is reproduced here (Fig. 1). This demonstrates the desirability of color photographs for the complex layer construction; Garner's publication (1963) suffers from the absence of color. Apart from these practical issues, Garner was looking for further samples or other analytical procedures. The first attempts to subject urushi to pyrolysis gas chromatography appear to have been successful. Furthermore, scanning electron micrographs increased the knowledge of the pigments used (Hornblower 1962) and Garner received radiographs of earlier lacquerware samples from Gettens. However, Garner also had unanalyzed samples returned to him and these were not the only failures. A manuscript prepared at his suggestion on the chemistry of urushi (Moss 1967) remained unpublished at the request of the author, and many scientists who had hitherto been of great use to him in his research denied him assistance because too great a commitment seemed to be required.

From his correspondence, Garner was also interested in questions of the pigmentation of the black layers, the composition of the black ground used in carved lacquerware, the choice of a suitable method of analysis, correct terminology for the Chinese sources of urushi, the lacquer tree that supplies urushi, and its spread over Asia, and the identification of the fabric support in the lacquerware of the Han era. At the same time he attempted to persuade various colleagues to study a translation he had prepared of the travel diaries of d'Incarville of 1760, which in fact appear to have been one of the most reliable contemporary reports.

Among Garner's papers, evidence can be found of two more experimental initiatives on additional lacquerware. Figure 2 shows the cross section of a carved lacquerware piece that has a construction typical of the Ming dynasty and will be discussed later. A further thin section shows for the first time the construction of a piece from the Han dynasty (206 B.C.-A.D. 220; Fig. 3). It has a thick layer of ground and a thin covering layer over four layers of fabric support.

Figure 1. Photomicrograph of a cross section from a Chinese lacquerware object, late sixteenth century, from the estate of Sir Harry Garner (Victoria and Albert Museum, London), taken by A.R. Sollars, Cranfield (magnification x50), supplied with the following commentary on the layer construction: "band 1: 2 layers brownish-red, moderately fine with large inclusions; band 2: 5 layers light red, fine; band 3: 4 layers bright red, coarse; band 4: 1 interface layer, discontinuous, fine layer, grayish; band 5: 1 layer dark gray or black, structureless compared with normal pigmented layers; band 6: 3 brownish-red, similar to band 1; band 7: light red, fine, similar to band 2; and band 8: bright red, coarse as band 3."

Figure 2. Fifteenth century, heavy black layer. A new photograph of a thin section from Garner's estate in transmitted light (16x). From bottom to top: wooden base; heavy black layer (mostly broken away); very thin transparent lacquer layer (looks orange); dark, yellow ground layers; black guide line (Garner 1963) looks transparent orange (see text); red ornamental zone. Figure 3. Thin section of a Han dynasty lacquerware object from Garner's estate.
The urushi debate

In order to clear up some misunderstandings and misinformation, we shall start with a discussion of some of the main aspects of debate.

Terminology
The first of these misunderstandings is the question of terminology, to which Garner applied himself in an attempt to discover a common approach in the natural sciences and the humanities to the origins of urushi (Burmester 1985). One glance at this theme in books and catalogs clearly demonstrates the need to establish an agreed terminology.

Identification of the lacquer tree as Rhus verniciflua or Toxicodendron verniciflua is in keeping with current botanical usage (see note 15; Zander 1972; Hora 1981; Schulze 1966). Hopefully, in the interests of simplicity, Rhus verniciflua will be adopted as the exclusive term.

It should be stressed—and this is also clear from Garner’s correspondence—that there is no information concerning the spread of Rhus verniciflua in the last three or four millennia. Analytical examination of the organic constituents of urushi itself may provide the answer to the question of whether Rhus verniciflua has always been the source of raw lacquer. The sap of other trees of the same genus, for example, Rhus succedanea, may also have been used.

The extent of the uncertainty about the chemical composition of lacquer can be seen in the range of ambiguous and even false designations that have been used. This is because modern scientific knowledge has hardly ever been applied to the relevant literature. An example of this is the use of the term “urushic acid” (see note 14), meaning the main ingredient of lacquer, which is also called “urushiol.” After its first description as “urushic acid” by Yoshida in 1883, it was described as “urushin” and “oxyurushin” in the paper of Tschirch and Stevens in 1905; these authors clearly wanted to demonstrate that the compound in question had nothing to do with acids in the chemical sense. In 1906 Miyama was the first to describe it as a phenol; then finally, in 1908, he used the designation “urushiol.” Since then it has been correctly and exclusively referred to in chemical literature as urushiol (for example, Majima 1909). Urushiol is in fact a mixture of phenols and can be taken as a trivial name for an entire group of chemically related compounds.

History and technology
It would appear reasonable to place Oriental lacquer within the range of known binding agents. Urushi can be considered as a colloidal system of a water-in-oil emulsion (Gettens and Stout 1966). Drops of water, containing polysaccharides and an enzyme, are dispersed within an oily phenol phase in which glycoproteins act as emulsifiers (Kumanotani 1979, 1983a, 1983b).

Chemical and physical analysis
As Garner and other scientists have already demonstrated, the natural sciences offer a starting point for the solution of technological problems associated with Oriental lacquerware, although Garner’s attempts to analyze the binding agent urushi were not successful. A study of the relevant literature shows that urushi does not form part of the classic analysis of binding agents which is concerned with oils, resins, waxes, gums, proteins, etc. 20 The analysis of urushi—and this is a complicating factor—must take account of its high degree of polymerization and cross-linking, and the addition of inorganic fillers and pigments and organic substances such as drying oils or glues. Although, thanks to the findings of Kumanotani (1979, 1983a, 1983b), our knowledge of freshly polymerized systems is relatively precise, there is no information on the effects of aging. Ideally, urushi should be analyzed after separation into its components; this is always the first step in the analysis of binding agents and
in the case of unhardened urushi. Unfortunately this is prevented by the insolubility of the polymeric system. The limited information supplied by infrared spectroscopy (Kumanotani 1979, 1983a, 1983b; Kenjo 1978) from systems which have not been separated shows that this step cannot be completely ignored. These and other analytical attempts show that our objectives must be modified to pursue analysis "in a quite empirical way, not even identifying components but trying to get distinguishable patterns."21 Here the possibility of thermal decomposition of the matrix comes to mind. This is achieved by breaking down the polymeric framework and permits analysis of the resulting fragments. But any conclusions about the matrix prior to decomposition still remain problematical.

There is a series of analytical possibilities associated with thermal decomposition of the polymeric framework, which promise to provide more information. The first experiments with pyrolysis gas chromatography carried out for Garner demonstrate this (see note 8). More extensive investigations have shown that pyrolysis mass spectrometry of Oriental lacquer (Burmester 1983a, 1983b), as well as of other natural polymers (Meuzelaar 1982), promises to produce interesting results. However, an interpretation is difficult beyond the level of accepting the results of analysis as a pattern. The introduction of multi-variable statistical evaluation has made progress in pattern recognition (Burmester 1983a, 1983b) but, without extensive preparatory investigations, comparative studies and relevant experience, the results must be treated with caution.

Along with the results already published, limited conclusions may be drawn from the mechanism and regularities of decay of the lacquer sample from its pyrolytic fingerprint in low resolution mass spectrometry (Burmester 1982, 1983c). In relation to questions posed by Garner, some interesting conclusions can be drawn from this experimental starting point. For example, the decomposition of urushi in the case of post-Tang (after a.d. 906) specimens seems to be very well defined. The expected decomposition pattern (Occolowitz 1964) is found in each of the pyrolysis mass spectra, but only in samples of similar age. This is in contrast to earlier lacquerware samples which obviously decompose in a much less defined manner.22 This may be due to alteration resulting from aging of the lacquer matrix or because the matrix was never structured in the same way as that of more recent carved lacquerwork. This immediately raises the question of whether a different method for preparation of urushi from Rhus verniciflua (kurome or nayashi) was used in earlier times or, indeed, whether another latex was used.

A more precise evaluation of the results can be achieved by improving the system of analysis (a switch from low- to high-resolution mass spectrometry). Computer-supported interpretation of these experimental results permits the identification of individual pyrolysis or ionization products which, in turn, in individual cases, give a clue as to the matrix before thermal decomposition. The experimental conditions for high-resolution mass spectrometry are similar to those already published for low resolution (Burmester 1983b). In order to establish results from this series of measurements on the same basis as those of previous investigations, measurements of samples already published were repeated (Burmester 1983b). The dates of the twenty-six samples, all from lacquer objects of the Linden-Museum (Stuttgart, German Federal Republic), ranged from Zhou to Qing and included a few modern ones. The information obtained so far is summarized.

If the high intensity peaks are filtered out from the mass spectra and related to the most probable combination of elements according to their mass (in this case only C, H, O) it is apparent that certain fragments23 can be observed in each of the samples investigated. These appear to be quasi "index fossils" that should permit recognition of urushi as a binding agent. As a limiting factor, I must admit that I had no opportunity to examine other saps of the genus Rhus.
It is striking that pre-Tang (before A.D. 618) specimens have a substantially higher proportion of carbohydrates (fragments of type \( C_n H_{2n} \)), while later samples comprise primarily oxygen-containing fragments (of the type \( C_n H_{2n}O_z \)). This supports the differences already mentioned in lacquerware according to its age.\(^{24}\)

In this section the construction of lacquerware is examined with the help of cross sections, and an attempt is made to determine the pigments used. Garner's publication of 1963 was a pioneering work on both of these points. However, the scope has been greatly increased in the present work.

I am indebted to the Linden-Museum, for generously allowing me to examine an extensive group of Chinese lacquerware as well as many pieces of carved lacquer. All the pieces investigated belong to this museum; they were purchased from the Fritz Löw-Beer Collection in 1978 (Burmester and Brandt 1982, Brandt 1982, 1986). The extensive scientific research project examined over forty objects, twenty-eight of which are presented here (Burmester and Brandt 1982).

**Methodology**

Small samples were taken from all the objects for the preparation of cross sections. By using laser microanalysis (Moenke, 1968; Roy 1979; Schrön 1983) it was possible to obtain an overall view of the pattern of elements detectable in the individual layers.\(^{25}\) In this way it was possible to avoid the difficulty, to which Garner referred, of preparing single layers for analysis. In association with microscopic evaluation of the cross sections\(^{26}\) it was possible to obtain an indication of the pigments used. Parts of the lacquer samples were pulverized for further investigation using mass spectrometry and x-ray diffraction analysis.\(^{27}\) Here, both Debye-Scherrer and vertical goniometric diffractograms were taken.\(^{28}\) Under suitable conditions, it was possible to identify the pigments used.

The Appendix contains the results obtained: the macroscopic construction of the pieces, the function of the individual layers, and their pigmentation. In keeping with Garner's method (1963), also reproduced along with the description of the object is the sequence of bands and layers,\(^{29}\) the color of the bands and their probable function, their approximate thickness (measured from the cross sections) and the pattern of elements obtained by laser microanalysis.

The group of early painted lacquerware pieces under investigation includes objects from the Zhou dynasty (nos. 1-5, see Appendix), the Han dynasty (nos. 6-10), the Tang dynasty (A.D. 618-906; nos. 11, 12), and the Song dynasty (no. 13; see also Figs. 4-18). These objects are discussed later in relation to their construction and function and also, in association with carved lacquerware, their pigmentation.

Most of the early painted lacquerware objects have a simple construction. In the case of object No. 1 from the Zhou era (Figs. 4,5) there is only one layer, which is considerably darkened on the surface, over a very thin ground layer. It is very difficult to determine if this was applied on purpose or whether, as has been observed in other cases, it results from residues of abrasives used.

The construction of the objects from the late Zhou and Han eras onwards can be schematized as follows: a ground mixed with coarse minerals (mostly with black additives), followed by one or more covering layers, and on the surface an ornamental, colored layer, usually red or black (Figs. 7,9,11,12,13,15). It is striking that none of the pieces under discussion display any evidence on the surface of the layers of having been worked upon. This indicates that after the drying process the films of lacquer were not rubbed down with abrasives. Plant fibers are often found in the individual layers (Fig. 5, yellow layer; Fig. 7, layer over the black ground). This suggests that the urushi was not filtered.
All the black grounds contain traces of minerals. Laser microanalysis has detected high intensities of silicon, calcium, iron, magnesium, titanium, manganese, and aluminum, while x-ray diffraction has identified the presence of quartz (SiO₂), gypsum (CaSO₄·2H₂O), calcium-magnesium or calcium-aluminum silicates, and calcium phosphates (Ca₅(PO₄)₃OH).

Further study provides the answer to the question of whether or not the typical brown coloring of the covering layers (visible in the cross sections of no. 2 in Fig. 7, no. 4 in Fig. 9 and no. 10 in Fig. 15) was pigmented. Laser microanalysis demonstrates that practically no elements other than calcium and magnesium are to be found in the brown covering layers of Han era objects. For the moment the question must remain open as to whether the top layer was altered due to aging of the binding agent or was intentionally modified.

Finally, we come to the lacquer painting of a golden bird on a black ground from the Tang dynasty (no. 11; Figs. 16, 17, 18; Mänchen-Helfen 1937a). This painting demonstrates several peculiarities in its pattern of elements and its cross section. It was not possible to explain the presence of gold in the dark layers of the black ground that appeared unpigmented under the microscope. The actual ornamental layer (Fig. 18) contains orpiment. The particles of metal visible in Figure 18 are tin, whereas silver foil could be detected in box no. 12 (Tang dynasty).

Although taking samples from carved lacquerware is substantially more difficult, it was possible to examine a number of pieces, one from the Yuan dynasty (1279-1368; no. 14; Figs. 19-21), ten from the Ming dynasty (nos. 15-25; Figs. 22-39) and three from the Qing dynasty (nos. 26-28; Figs. 40-42). In the case of nos. 16 and 18 sampling was restricted to the stand ring. Here, because of the ever-present possibility of overpainting, information on pigmentation could only be assessed with reservation.

While I am aware of the dangers of schematization, it appears feasible in the case of the objects examined here (mainly from the Ming dynasty), which had a number of features in common. The construction of these pieces can be described by a simple system of three functional zones: the base, a two-part ground, and an ornamental zone above that. On top of the base there is usually a thick layer of coarse, black ground. On top of that, there are three or four layers of a much harder and finer ground which is often yellow, or in any event a color different from that of the ornamental zone. Over this lie numerous lacquer bands, often with different pigmentations, which form a comparatively inelastic ornamental zone (Figs. 20, 23, 26, 29, 31, 32, 34, 39).

One might expect conservation and restoration problems similar to those found in panel painting and polychrome sculpture due to the conflicting properties of the mobile base and the immobile lacquer layers above. However, carved lacquerware is far less sensitive to variations in temperature and humidity than one would think (see section 5).
Figure 4. No. 1, wooden pedestal, China, end of Zhou dynasty (fifth-third century B.C.), Linden-Museum, Stuttgart (OA 20.739LA).

Figure 5. Cross section of no. 1 (Fig. 4; x160).

Figure 6. No. 2, two-eared cup, China, Zhan Guo era (fourth-third century B.C.; LMS OA 20.731L).

Figure 7. Cross section of no. 2 (Fig. 6; x32). The two laser craters are clearly visible here, as in the following photographs. The position of the craters permits the pattern of elements to be matched to its layer.

Figure 8. No. 4, round lidded box, China, late Zhou, beginning of Western Han dynasty, (c. second half of third century B.C.; LMS 20.720.L).

Figure 9. Cross section of No. 4 (Fig. 8; x32).
Figure 10. No. 8, two-eared cup, China, Eastern Han dynasty (100 B.C.–A.D. 100; LMS OA 20.736L).

Figure 11. Cross section of no. 8 (Fig. 10; x160).

Figure 12. Cross section of No. 9 (not illustrated), two-eared cup, China, Han dynasty (100 B.C.–A.D. 100; LMS OA 20.735L; x80).

Figure 13. As for Figure 12, but in polarized light. The sequence of layers is clearly visible (x80).

Figure 14. No. 10, bowl, China, first half of the Eastern Han dynasty (first century; LMS OA 20.7301).

Figure 15. Cross section of No. 10 (Fig. 14; x63).
Figure 16. No. 11, lacquer painting, China, Tang dynasty (possibly later; LMS OA 20.848 a-3L).
Figure 17. Cross section of No. 11 (Fig. 16) in partly polarized light (x16).
Figure 18. Part of the cross section of no. 11 (Fig. 17), showing the uppermost layers (x200).

Figure 19. No. 14, bowl on stand, China, Yuan dynasty, probably fourteenth century (LMS OA 20.825a-bL).
Figure 20. Cross section of No. 14 (Fig. 19; x16).
Figure 21. Part of the cross section of no. 14 (Fig. 20) showing the lowest layers (x32).

Figure 22. No. 15, plate, China, Ming dynasty (late fourteenth–early fifteenth century; LMS OA 20.824L).
Figure 23. Cross section of No. 15 (Fig. 22; x32).
Figure 24. Part of the cross section of No. 15 (Fig. 23), showing the yellow ground layers (x63).
Figure 25. No. 19, large chest, China, Ming dynasty, Jiajing era (1522–1566) (LMS OA 20.761L).
Figure 26. Cross section of no. 19 (Fig. 25), upper layers (x16).
Figure 27. Cross section of no. 19 (Fig. 25), lower layers (x40).

Figure 28. No. 21, plate, China, Ming dynasty, Wanli era, dated 1592 (LMA OA 20.756L).
Figure 29. Cross section of no. 21 (Fig. 28; x32).

Figure 30. No. 22, box, China, Ming dynasty (second half of sixteenth century; LMS OA 20.763L).
Figure 31. Cross section of no. 22 (Fig. 30; x16). The position of the laser crater has been made visible with a white substance.
Figure 32. Part of the cross section of no. 22 (Fig. 31), showing the yellow ground layers and above them the black guide line (Gomer 1963; x63).
Figure 33. No. 23, box, China, Ming dynasty, Wanli era (1573–1619; LMS OA 20.819L).
Figure 34. Cross section of no. 23 (Fig. 33; x32).

Figure 35. No. 24, box, China, probably seventeenth century (LMS OA 20.765L).
Figure 36. Cross section of no. 24 (Fig. 35; x16).
Figure 37. Cross section of no. 24 (Fig. 35) in polarized light. The individual layers are clearly recognizable (x16).

Figure 38. No. 25, box, China, probably from the end of the Ming dynasty (sixteenth–seventeenth century; LMS OA 20.817L).
Figure 39. Cross section of no. 25 (Fig. 38; x32).
1. Bases and supports

This study can say little about the nature of the base, that is, the type of wood used, even though x-rays appear to give very interesting results (Shosoin Office 1975). This is because cinnabar (the predominant pigment in the later objects) strongly absorbs x-rays (Rees-Jones 1975) and therefore the graining of the wooden base is very difficult to identify. Nonetheless, since x-ray investigations (unlike many older methods) do not damage the objects, they should not be forgotten, and an x-ray survey of the pieces is planned. The same reservation applies to the fabric often laid on top of the base (see Fig. 21, just visible at the bottom of the picture), which on intact pieces cannot be visually examined and sampled.

2. Black ground: construction, function, and pigmentation

The lowest black ground contains mineral additives. High intensities of silicon, calcium, manganese, aluminum, titanium, iron, and magnesium indicate the use of dark earths, ashes, or clays. According to experimental results, their proportion must be very high. The thickness of this layer is very striking and is often mentioned by Garner in his correspondence. This must have extended the drying time, as well as prevented the formation of an urushi matrix without defects. However, it also leveled out any unevenness in the base below. Microscopic investigation does not reveal how many layers of this black ground were applied.

3. Yellow ground: construction and function

In the series of pieces investigated from the Yuan and Ming dynasties, a further zone of ground is found above the thick black one. This zone consists of several layers; it is usually yellow (nos. 14, 15, 21, 22, 23, 25 and Figs. 20, 21, 23, 24, 29, 32, 34, 39) or occasionally another color that in any case contrasts with the ornamental bands on top (brown-black in no. 19, Figs. 26, 27, and black in no. 24, Figs. 36, 37).

In contrast to the zone underneath, the proportion of binding agent is much higher in comparison to that of pigment and other material discussed later. This should result in increased stability. From a visual appraisal, it seems as though the surfaces of the layers have been very carefully worked (Figs. 21, 24, 32). This cannot be observed to such a great extent in the black zone beneath, and anyway is difficult to see because of the greater coarseness.

The first function of the yellow ground is to provide an additional leveling out of any unevenness in the black, coarse ground. Without this zone the layers above would follow any unevenness, which would greatly disturb the aesthetic

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Figure 40. No. 28, box, China, Qing dynasty, dated 1775 (LMA OA 20.787L).
Figure 41. Cross section of no. 28 (Fig. 40; x16).
Figure 42. Part of cross section of no. 28 (Fig. 41); here the red layers were pigmented with vermilion (x63).
impression, especially in carved lacquerware with a different pigmentation of the ornamental zone.

Secondly, these layers absorb mechanical shearing forces between the wooden base and the ornamental zone. (The black zone below actually fulfills this function to an even greater extent.) The fact that these shearing forces often occur is mentioned in manuscripts from the fourteenth and fifteenth centuries which tell of the damage typical of carved lacquerware.\textsuperscript{34}

The third function lies in conveying an optical impression of depth and at the same time in emphasizing the contours of the ornamentation because, in general, the yellow ground is exposed during carving in works of the Ming era, giving the impression that the ornamentation is painted on. The absence of this effect of depth on Qing dynasty piece no. 28 (Fig. 40) may account for its flatness and lifelessness, qualities also observed in pieces from the Ming era which are in need of cleaning.

A fourth and final function of the contrasting coloration of this zone was to aid the craftsman by giving him an indication of the maximum permitted cutting depth. After application and drying of the various layers, carving had to be done with extraordinary precision, as corrections were hardly possible. Therefore, it was of great importance that the depth of carving was uniform; the increased number of yellow layers permitted a certain, if limited, tolerance. The rubbing down of the surface of the black and yellow layers, already referred to, helped to maintain a uniform cutting depth.

4. Yellow ground: pigmentation

There is evidence of arsenic\textsuperscript{35} as a color-producing pigment in the yellow layers; diffractometric results on nos. 14, 15, 18, and 21 all clearly prove the use of orpiment (As\textsubscript{2}S\textsubscript{3}). The presence of calcium, magnesium, silicon, iron, mercury, aluminum, and manganese (listed here in order of their frequency, and most conspicuous in no. 21) point to a natural origin (Wallert 1984; Schafer 1955), whereby all these elements can be correlated to associated minerals (Schröcke 1981; Doelter 1926). Therefore it seems unlikely that synthetic orpiment (Wallert 1984; Schafer 1955) was used on the objects cited above. The presence of mercury can be explained by the natural admixture of cinnabar (Wallert 1984).\textsuperscript{36} The earliest evidence of orpiment, within the limits of this investigation, can be traced to piece no. 11 from the Tang era. In the case of carved lacquerware the evidence starts with no. 14 from the Yuan era and continues through to the Qing dynasty.

The literature shows that orpiment was used in Chinese painting from the ninth–tenth centuries A.D. (Winter 1984). Before that, yellow ochre and natural organic yellow pigments in China (Winter 1984; Gettens 1938–39) and also in Japan (Goffer 1980:177–179; Yamasaki 1979; FitzHugh 1979; Gettens 1976:241–252) were dominant from the beginning of the first century A.D. In Japan, orpiment was used frequently after the middle of the seventeenth century. Yonezawa (1956) gives some references to historical sources from the Six Dynasties onwards and refers to inland deposits in Southern China;\textsuperscript{37} in fact the same regions in which there are large urushi plantations today. These key dates may, in association with the results of the present investigations, help to date and perhaps even to identify imitations.

5. The ornamental zone: construction and function

The ornamental zone shows a huge range of styles as can be seen in Figures 20, 23, 26, 31, 36, 39, 41. Because of the slightly inhomogeneous distribution of pigments in the binding agent, the microscope reveals the differentiation between individual layers of lacquer, also clearly visible in the illustrations.
The condition of the surface of the layers in the cross sections sometimes suggests that very thorough treatment took place after the drying process. Exceptions are corners, edges, and heavily rounded sections, where working would be naturally more difficult and less regular. It is rare to encounter remains of abrasive materials such as in no. 14 (Fig. 21) which appear to have become embedded in layers which were not quite dry.

There is a great diversity in the literature on Chinese carved lacquerware about the number of layers involved. Estimates—and this is what is being discussed here—vary between a few and over 300 (Burmester and Brandt 1982). Garner attempts greater precision when he writes “the thickness of individual layers is in the order of 0.3 mm or less” and “between one and two hundred layers” (Garner 1979). Microscopic investigation of the pieces examined here permits a much more exact idea. If all the lacquer bands are included in the calculation, this gives an average thickness per layer of approximately 4μm.

Because of the many and various techniques which are dealt with in standard works on the subject, the question of further functions of the ornamental zone is not discussed here; it is obvious that this zone is open to visual examination (Garner 1979; Lee 1972; Kuwayama 1982).

The well thought out construction described above prevents variations in the moisture content of the base. Gain or loss of moisture is made extremely difficult due to the homogeneous, polymeric, and hydrophobic character of the lacquer layers. This explains the surprisingly good condition of some Chinese carved lacquerware. If a piece sustains mechanical damage, however, moisture can enter or leave, rapidly causing extensive damage because of the movement of the base against the immobile ornamental zone.

6. The ornamental zone: pigmentation of the red layers

In the pieces examined—the early lacquerware and the carved lacquerware—mercury is found in the red pigmented layer almost without exception. This, together with the results of x-ray diffraction of samples from objects nos. 2, 4–6, 8, 9, 12, 13, 15, 16, 18–26, and 28, proves that cinnabar (cinnabarite, beta-HgS) was used as a pigment.

Apart from mercury, other elements present (in order of frequency of occurrence) are calcium, magnesium, iron, silicon, manganese, arsenic, aluminum, barium, titanium, copper, chromium, and lead. These can be correlated to minerals associated with cinnabar (Schrocke 1981; Doelter 1926). The detection of this type of natural admixture using diffractometry proved to be possible on a few objects. However, an unambiguous matching was not achieved because it was not possible—for experimental reasons—to isolate only the red layers, that is, those which had been pigmented with cinnabar.

While it is possible to assume, from the impurities detected, that natural cinnabar was used in the majority of the pieces (nos. 15–23), this is not valid for the late Ming and Qing pieces (nos. 24–28). Apart from mercury, only calcium and magnesium could be detected, and these can be attributed to the binding agent itself. The absence of accompanying elements proves the application of vermillion, a synthetic cinnabar produced by repeated sublimation. In relation to the dating of the pieces examined, this would indicate a change in the use of this important pigment from the seventeenth century onwards, and may be significant in providing further help in dating lacquerware. In pieces nos. 26 and 27 arsenic is also found, here certainly as orpiment. It is conceivable that in the purification of cinnabar by repeated sublimation, orpiment was carried through as an impurity. This is only possible for orpiment because it sublimes easily; it does not apply to other naturally associated minerals.
Data from the literature are very variable concerning the vermillion made from mercury and sulfur in the so-called dry process. Gettens (1972) says that the Chinese may have invented this process and that the earliest evidence for it is in the seventh century A.D. According to Needham (1976), the first written reference can be found as early as the fifth century B.C. From his comments, based on numerous sources, it is evident that cinnabar and mercury (often obtained from cinnabar) were the mainstays of Chinese alchemy and the related world of ideas. Therefore, it seems plausible that even before the seventh century, alchemists had made the observation that in the cooler areas of the experimental apparatus (ovens, furnaces, etc.) there were traces of a red substance—vermillion, resulting from sublimation. When this developed into a systematic process remains an open question.

Yamasaki (1979) reports vermillion being produced in Japan in 1609. According to Oguchi (1969), the synthetic pigment was widespread during the Edo period. These dates are compatible with the findings of the present investigation. Clear evidence of synthetic cinnabar in no. 17 supports the doubts expressed by art historians over dating the piece to the fifteenth century and identifying it as Chinese. It is more likely to be a later Japanese imitation of Chinese carved lacquerware.

In none of the cross sections was there a blackening of the red cinnabar when transformed into metacinnabar as discussed later on (Gettens 1972). Urushii appears to stabilize the pigment as well as an oily binding agent would do. The fact that this transformation can be observed is shown by the black coronae around the laser craters in Figures 23, 36, and 41. Black metacinnabar has formed here.

Compared with cinnabar, the other red pigments play a wholly subordinate role. Red iron oxide (haematite) was used as pigmentation in no. 14, in no. 19 in both upper layers, and in no. 26. In nos. 14 and 26, the evidence could be secured by diffractometry. The choice of iron oxide was certainly due to its dull red tone, which differentiated it from the red of the surrounding layers derived from the presence of cinnabar. The pattern of elements in these dull red layers is especially pure. In particular, the pattern of no. 14 indicates very pure iron oxide, which was applied mixed with cinnabar in the other two cases.

The evidence of chromium in nos. 22 and 24 (Figs. 31, 36, uppermost dark red layers) is puzzling; chromium pigments have only been known since the nineteenth century, so maybe this can be explained by restoration work.

7. The ornamental zone: pigmentation of the black layers

The pigmentation of the black layers of the lacquerware examined here requires more detailed consideration.

Once again, laser microanalysis offers clues as to the type of black pigments used. In the black layers there are remarkably frequent instances of iron, mercury, or spectra that are very low in elements and intensity.

In the case of opaque pigmentation of the black layers (nos. 22 and 23), the evidence indicates that iron must be present as black iron pigments (as oxides or hydroxides), although it was not possible to support this by diffractometry.

For nos. 1, 8, 12, and 19 black metacinnabar could have been used in the opaque black layers. This is indicated by the presence of mercury, found by laser microanalysis, and proved additionally by x-ray diffractometry of nos. 1 and 19. This result is very interesting because, as far as I know, metacinnabar has only been found once and confirmed by diffractometric analysis in a grave from the Han dynasty (Winter 1984).

It is obvious from the genesis of cinnabar and metacinnabar, as well as from the description of their deposits, that they are found associated as natural minerals. Furthermore, to the naked eye they are almost impossible to tell apart. If cinnabar is present as large crystals or crystal aggregates, then it is dark red, almost black. Only
after grinding will it become "cinnabar red." However, this means that a proportion of the minerals found in the natural deposits, that is, metacinnabar, remains black on grinding. Metacinnabar becomes red on heating, and mercury can also be obtained this way, so metacinnabar certainly had the same importance in alchemy as cinnabar or mercury. For these reasons, metacinnabar would have been an obvious choice as a black pigment; this is confirmed by the present findings.

However, in the remaining three pieces, nos. 14, 24, and 25, the black layers are transparent and, in addition to a similar brown-black coloration, only rarely contain small aggregates of black pigment (for example, no. 14, Figs. 20,21). The piece pictured in Figure 2 from Garner's estate shows a layer of similar appearance which, from its function, is referred to as a black guideline (Garner 1963, 1979; Burmester and Brandt 1982; see also Fig. 32). Garner's cross section in transmitted light shows the transparent character particularly clearly. In all these cases, the addition of carbon black can be assumed; this would explain the weak concentration of elements detected by laser microanalysis. Garner had already guessed as much and it can also be seen in many other objects of Far Eastern art (Winter 1984). Along with the use of soot or lamp black (Gettens 1938–39), the admixture of Chinese ink should also be considered. Thus Chiang-Yen (Yonezawa 1956) refers to Chinese ink as a dye as early as the fifth century, and Winter (1974) introduces other sources. Gettens (1976) and Yamasaki (1979) both name Chinese ink as the only black pigment in Japanese paintings. It is very interesting that Chinese ink (or more appropriately the glue used in its preparation) and urushi have a very similar pH (4–5; Reinhammar 1970). This has a positive effect on the compatibility of the ink with urushi. Because the hydrophobic character of soot would make it unsuitable as the only additive, it is better to mix it into hydrophilic glue which then stabilizes the colloidal system (Winter 1974). In connection with this there is an interesting reference in a source manuscript of Shen Chi-sun who reports the production of Chinese ink by combustion of urushi lacquer (Vaultier 1957).

A summary of all the pigments used in Chinese lacquerware investigated here gives for yellow, orpiment (As₂S₃) and for red tones, cinnabar (beta-HgS) and occasionally haematite (Fe₂O₃). For black hues there are metacinnabar (alpha-HgS), black iron pigments and carbon black as Chinese ink. Silver and tin have been detected as metal inlays. It is remarkable that none of the known blue and green pigments has been used.

In Winter's summary (1984), reference is made to the frequent application of other pigments in Chinese objects with other binding agent systems: for white, chalk (CaCO₃) and "lead white" (2PbCO₃·Pb(OH)₂ and PbSO₄), for blue, azurite (2CuCO₃·Cu(OH)₂) and for green, malachite (CuCO₃·Cu(OH)₂) and copper chloride (Cu₂(OH)₃Cl parataramite and atacamite), though the presence of PbSO₄ and Cu₂(OH)₃Cl was exceptional.

Why are all these very common pigments not found in Chinese lacquerware? A few experiments, as well as reports from craftsmen, have demonstrated that chalk, lead white, azurite and malachite decompose in the binding agent urushi, that is they are unstable. The reason lies in the more acidic pH value of urushi: approximately 4.6 (Kenjo 1976) and 4.2 to 5.3 (Oshima 1985). This more acidic medium causes a chemical reaction which decomposes the pigment and gives a more basic pH value. This in turn deactivates the enzyme laccase (Reinhammar 1970), disturbs the equilibrium in the phenol-water emulsion and therefore hinders the drying of the urushi film (Kenjo 1976). The incompatibility of urushi with a large range of common pigments results in an inevitable limitation of colors used in Chinese lacquerwork.
I have already mentioned that cinnabar has a function as a reagent (Needham 1976) as well as a provider of color. It occupied a central role in the alchemy of ancient China, in daily life as well as in the Chinese spiritual world. Schafer (1955) assigns a similar role to orpiment. Because both cinnabar and orpiment can be repeatedly sublimed, they are bound closely to the concept of material immortality (Needham 1976). Objects made with urushi were regarded in the same way, as shown both by the great value placed upon them by the highest levels of society—including the imperial court—and by the fact that their production was, for a time, under state control (Garner 1979). Furthermore, lacquerware objects found in graves from the Han dynasty lasted until the Ming era and longer. This must have invested urushi with the mystical qualities of material immortality. The “mystery” surrounding urushi still disrupts the debate between east and west in matters of conservation and restoration. This combination of circumstances certainly did not go unnoticed and accounts for the unchanging high regard for urushi, cinnabar, and orpiment over a very long period.

Acknowledgments

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Appendix

In the following section the results of microscopy and laser microanalysis are combined. For details of the methods of sampling see an earlier publication (Burmester and Brandt 1982). The cross sections, most of which are shown in Figures 4-42, were systematized in the following way. Each cross section contains lacquer bands (see note 29) A,B,C ... (first column), which are on either a wooden or a fabric base (T). Each band can incorporate n lacquer layers (see note 29) and is then referred to as nx (for example, 3D in the event that band D has three layers). In the second column a crude color is mentioned, in the third the function of the band and in the fourth its approximate thickness in μm (if not measurable, marked as *). The last column gives the pattern of elements provided by laser microanalysis; the subscript numbers indicate the estimated intensity of the spectral lines from “only recognizable with difficulty” to “stronger than normal” and “auto reversal.” In cases where the laser beam did not penetrate exactly into a band, comments as to the positioning are given (for example, 80%A, 20%B, if 80% of the laser crater lies in band A). For technical reasons, memory effects could not be excluded in all cases.
### Chinese lacquerware

1. **Wooden pedestal, China, end of Zhou (fifth-third century B.C.; Linden-Museum, Stuttgart, West Germany, OA 20.739A)**
   - **A** black ground
   - **B** sand color
   - **C** black

   - **A** black ground
   - **B** sand color
   - **C** brown
   - **D** brown

3. **Lid of a vessel, China, end of Zhou (fourth-third century B.C.; Linden-Museum, Stuttgart OA 20.738L; Brandt 1986)**
   - **A** black ground
   - **B** sand ground
   - **C** black

4. **Round lidded box, China, late Zhou/beginning of Western Han (c. second half of third century B.C.; Linden-Museum, Stuttgart OA 20.720L; Brandt 1982, 1986)**
   - **A** black ground
   - **B** brown
   - **C** red
   - **D** brown

5. **Lid of a wine beaker of the "lian" type, China, probably Qin (227-206 B.C.; Linden-Museum, Stuttgart OA 20.719L)**
   - **A** brown-black ground
   - **B** brown
   - **C** red

6. **Internal construction of a box, China, Han dynasty, probably second half of second century B.C. (Linden-Museum, Stuttgart OA 20.721C)**
   - **A** brown-black ground
   - **B** brown
   - **C** red
   - **D** wooded core

7. **Cylinder-shaped container, China, probably Western Han (200-100 B.C.; Linden-Museum, Stuttgart OA 20.722L)**
   - **A** brown ground
   - **B** brown
   - **C** red
   - **D** black

8. **Two-eared cup, China, Eastern Han (100 B.C. - A.D. 100; Linden-Museum, Stuttgart OA 20.736L)**
   - **A** black ground
   - **B** brown

9. **Two-eared cup, China, Han dynasty (100 B.C. - A.D. 100; Linden-Museum, Stuttgart OA 20.735L)**
   - **A** black ground
   - **B** black
   - **C** red
   - **D** black

10. **Bowl, China, first half Eastern Han era (first century; Linden-Museum, Stuttgart OA 20.730L; Brandt 1986)**
    - **A** black ground
    - **B** brown
    - **C** red ornament

---

<table>
<thead>
<tr>
<th>Material</th>
<th>Composition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black ground</td>
<td>Si, Fe, Mg, Al, Ca, Ti, Hg, Mn</td>
<td>Ca, Si, Ti, Mg, Fe</td>
</tr>
<tr>
<td>Sand color</td>
<td></td>
<td>Ca, Si, Fe, Hg, Mg, Si</td>
</tr>
<tr>
<td>Black</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown</td>
<td></td>
<td>Ca, Mg</td>
</tr>
<tr>
<td>Red ornament</td>
<td></td>
<td>Hg</td>
</tr>
<tr>
<td>Wooden core</td>
<td></td>
<td>Ca, Hg, Fe, Mg, Si</td>
</tr>
<tr>
<td>Red</td>
<td></td>
<td>Ca, Ba, Ca, Mg, Hg</td>
</tr>
<tr>
<td>Ornament</td>
<td></td>
<td>Ba, Ca, Ca, Hg</td>
</tr>
<tr>
<td>Ornaments</td>
<td></td>
<td>Ba, Ca, Hg, Fe, Mg, Si</td>
</tr>
<tr>
<td>Wooden core</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11. Seven lacquer paintings with gold-colored bird on a dark background, China, Tang dynasty, possibly later (Linden-Museum, Stuttgart OA 20.848a-5l; Brandt 1986)

from the surface of the painting:

| A  | black ground          | Si₆, Ca₆, Fe₆, Mg₆, Ti₂, Mn₂, Al₂ |
| B  | clear lacquer         | 70 Ca₄, Sn₄, Mg₄ |
| C  | clear lacquer         | 50 |

from the painting:

| A  | brown-black ground    | Si₆, Ca₆, Fe₆, Mg₆, Ti₂, Al₂, Mn₂ |
| B  | brown base            | 170 Au₂, Ca₁ |
| C  | sand ornament         | 90 Sn₄, Ca₄, As₃, Mg₄, Si₄, Fe₁ |
| D  | clear lacquer         | 25 |
| E  | clear lacquer         | 15 |

12. Heavily damaged lid or lower part of a box, China, Tang, c. eighth century (Linden-Museum, Stuttgart OA 20.744L; Brandt 1986)

| T  | wooden core           |  |
| 27| black ground          | 440 Ca₅, Si₅, Fe₅, Mg₅, Al₂, Ag₂, Hg₁ |
| | brown base            | 60 Ca₅, Ag₂, Hg₂ |
| | red ornament          | 50 Ca₅, Ag₂, Hg₂ |

13. Small petal-edged bowl with flat bottom, China, Song dynasty, c. twelfth-thirteenth century (Linden-Museum, Stuttgart OA 20.746L)

| T  | ground                |  |
| A  | black                 |  |
| B  | clear lacquer         | 25 Ca₅, Mg₅, Fe₅, Mn₅, Al₁, Si₁ |
| C  | red ornament          | 30 |


| T  | ground                |  |
| A  | black                 |  |
| 4B| yellow ground         | 200 Ca₅, As₅, Mg₅ |
| 7C| black                 | 230 Ca₅, Mg₅ |
| 3D| red                   | 150 Ca₅, Fe₅, Mg₅ |
| 4E| black                 | 260 Ca₅, Mg₅ |
| 2F| red                   | 200 Ca₅, Fe₅, Mg₅ |
| 6G| black                 | 250 Ca₁ |

15. Plate, China, Ming dynasty, late fourteenth–early fifteenth century (Linden-Museum, Stuttgart OA 20.824L)

| T  | ground                |  |
| A  | black                 |  |
| 4C| yellow ground         | 360 As₅, Hg₅, Ca₂ |
| 7D| red                   | 390 90% Hg₅, 10% Fe₅, Ca₅, Mg₅, Al₁, Si₁ |
| 7F| red                   | 280 |
| 7H| red                   | 170 Hg₅, Ca₅, Fe₅, Mg₅, Al₁, Si₁ |
| 10N| red                   | 380 |

16. Box, China, Ming dynasty, Yongle era (1403–1424; Linden-Museum, Stuttgart OA 20.753L; Brandt 1982, 1986)

| T  | ground                |  |
| A  | red layer             | Hg₅, Ca₅, Fe₅, Mg₅, Si₁ |
17. Large plate, China, Ming dynasty, second half of fifteenth century (Linden-Museum, Stuttgart OA 20.7541); this could also be considerably later and of Japanese origin

<table>
<thead>
<tr>
<th>Layer Type</th>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black layer</td>
<td>Hg₆, Ca₃, Mg₂ (contaminated with red layer by 30%)</td>
</tr>
<tr>
<td>Numerous red layers</td>
<td>Hg₆, Ca₃, Mg₂</td>
</tr>
<tr>
<td>Aggregate of pigment in red layer</td>
<td>Hg₆, Ca₃, Mg₂</td>
</tr>
</tbody>
</table>

18. Bowl, China, Ming dynasty, Jiajing era (1522–1566; Linden-Museum, Stuttgart OA 20.7961)

<table>
<thead>
<tr>
<th>Ground Type</th>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>Ca₆, Hg₂</td>
</tr>
<tr>
<td>Yellow-brown</td>
<td>&lt;180</td>
</tr>
</tbody>
</table>

C black

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>650</td>
<td>Hg₆, Ca₃, Mg₂, Mn₂, Si, Fe₁</td>
</tr>
<tr>
<td>110</td>
<td>Hg₆, Ca₃, Mn₂, Mg₂, Ca₂, Si, Fe₁</td>
</tr>
</tbody>
</table>

19. Large chest, China, Ming dynasty, Jiajing era (1522–1566; Linden-Museum, Stuttgart OA 20.7611; Brandt 1986)

<table>
<thead>
<tr>
<th>Ground Type</th>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>Ca₆, Hg₃</td>
</tr>
<tr>
<td>Brown</td>
<td>60</td>
</tr>
<tr>
<td>Black</td>
<td>240</td>
</tr>
<tr>
<td>Red</td>
<td>1040</td>
</tr>
<tr>
<td>Brown</td>
<td>320</td>
</tr>
<tr>
<td>Dark red</td>
<td>80</td>
</tr>
</tbody>
</table>

20. Large round box with multicolored carved lacquer, China, Ming dynasty, Wanli era, dated 1586 (Linden-Museum, Stuttgart OA 20.8071; Brandt, 1982, 1986)

<table>
<thead>
<tr>
<th>Ground Type</th>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>Si₂, Ca₆, Fe₆, Mg₂, Ti₃, Mn₂, Al₂, Hg₂</td>
</tr>
<tr>
<td>Red</td>
<td>10%A, 90%B: Ca₆, Hg₆, Mg₂, Si₂, Mn₂, Fe₃</td>
</tr>
<tr>
<td>Yellow</td>
<td>120</td>
</tr>
</tbody>
</table>

21. Large plate with seven dragon medallions, China, Ming dynasty, Wanli era, dated 1592 (Linden-Museum, Stuttgart OA 20.7561; Brandt, 1982, 1986)

<table>
<thead>
<tr>
<th>Ground Type</th>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>140</td>
</tr>
<tr>
<td>Red</td>
<td>&gt;430</td>
</tr>
</tbody>
</table>

22. Octagonal box, China, Ming dynasty, second half of sixteenth century; Linden-Museum, Stuttgart OA 20.7631; Brandt 1986)

<table>
<thead>
<tr>
<th>Ground Type</th>
<th>Chemical Composition</th>
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<tbody>
<tr>
<td>Black</td>
<td>Si₂, Ca₆, Fe₆, Mg₂, Al₂, Ti₃, Mn₂, Hg₂</td>
</tr>
<tr>
<td>Yellow</td>
<td>Ca₆, Mn₂, Si, Mn₂, Al₂, Mg₂, Fe₆, Hg₂</td>
</tr>
<tr>
<td>Red</td>
<td>80%O, 20%: Ca₆, Fe₆, Mg₂, Mn₂, Si, Mn₂</td>
</tr>
<tr>
<td>Dark red</td>
<td>90</td>
</tr>
</tbody>
</table>

23. Rectangular lidded box, China, Ming dynasty, Wanli era (1573–1619; Linden-Museum, Stuttgart OA 20.8191; Brandt 1988)

<table>
<thead>
<tr>
<th>Ground Type</th>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>Si₂, Ca₆, Fe₆, Mg₂, Al₂, Mn₂, Hg₂</td>
</tr>
<tr>
<td>Yellow</td>
<td>190</td>
</tr>
<tr>
<td>Red</td>
<td>250</td>
</tr>
<tr>
<td>Dark red</td>
<td>340</td>
</tr>
<tr>
<td>Black</td>
<td>340</td>
</tr>
<tr>
<td>Red</td>
<td>65</td>
</tr>
<tr>
<td>Black</td>
<td>250</td>
</tr>
<tr>
<td>Red</td>
<td>65</td>
</tr>
<tr>
<td>Black</td>
<td>340</td>
</tr>
<tr>
<td>Red</td>
<td>65</td>
</tr>
<tr>
<td>Dark red</td>
<td>110</td>
</tr>
</tbody>
</table>
24. Rectangular box, China, probably seventeenth century (Linden-Museum, Stuttgart OA 20.7851)

<table>
<thead>
<tr>
<th>Code</th>
<th>Color</th>
<th>Interior</th>
<th>Ground</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2B'</td>
<td>black</td>
<td>60</td>
<td>&gt;850</td>
<td>Ca, Si</td>
</tr>
<tr>
<td>2C'</td>
<td>black</td>
<td>50</td>
<td>180</td>
<td>Ca, Fe, Mg, Mn, Al, Si</td>
</tr>
<tr>
<td>9D</td>
<td>red-brown</td>
<td>425</td>
<td></td>
<td>Ca, Hg</td>
</tr>
<tr>
<td>2E</td>
<td>light red</td>
<td>85</td>
<td></td>
<td>Hg, Ca, Mg</td>
</tr>
</tbody>
</table>

B: black ground

25. Rectangular box, probably China, probably end of Ming dynasty, sixteenth-seventeenth century (Linden-Museum, Stuttgart OA 20.8171)

<table>
<thead>
<tr>
<th>Code</th>
<th>Color</th>
<th>Ground</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C</td>
<td>yellow</td>
<td>150</td>
<td>As, Ca, Hg, Mg, Si, Fe</td>
</tr>
<tr>
<td>5D</td>
<td>red</td>
<td>210</td>
<td>Si, Ca, Hg, Fe, As, Hg, Ca</td>
</tr>
<tr>
<td>5F</td>
<td>black</td>
<td>290</td>
<td>Ca, Hg, Hg, Ca, Sr, As</td>
</tr>
<tr>
<td>5H</td>
<td>red</td>
<td>250</td>
<td>Hg, Ca, Sr, As</td>
</tr>
<tr>
<td>5J</td>
<td>black</td>
<td>235</td>
<td>Ca, Hg</td>
</tr>
<tr>
<td>5L</td>
<td>black</td>
<td>290</td>
<td></td>
</tr>
<tr>
<td>7N</td>
<td>black</td>
<td>290</td>
<td></td>
</tr>
</tbody>
</table>

26. Large table with carved lacquerwork, late seventeenth-early eighteenth century (Linden-Museum, Stuttgart OA 20.7481); samples taken from the upper surface of the table, small particles without ground.

<table>
<thead>
<tr>
<th>Code</th>
<th>Color</th>
<th>Ground</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>numerous red layers alternating</td>
<td>red: Fe, As, Hg, Ca, Mg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with red brown layers</td>
<td>red-brown: Fe, Ca, Hg, Mg, Mn</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>numerous ground layers</td>
<td>Ca, Mg, As, Sr, Mn, Al, Fe</td>
<td></td>
</tr>
<tr>
<td></td>
<td>numerous red layers</td>
<td>Hg, As, Ca, Mg</td>
<td></td>
</tr>
</tbody>
</table>

28. Twelve-cornered box, China, Qing dynasty, dated 1775 (Linden-Museum, Stuttgart OA 20.7871)

<table>
<thead>
<tr>
<th>Code</th>
<th>Color</th>
<th>Ground</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2B</td>
<td>black</td>
<td>&gt;20B</td>
<td>Ca</td>
</tr>
<tr>
<td>2C</td>
<td>red</td>
<td>485</td>
<td>Ca, Hg</td>
</tr>
</tbody>
</table>

2. The results were communicated to Garner by E.W.S. Press, Director of Chemical Inspection, War Office, London, dated 4.12.61 and 30.10.62.


4. For example, in a letter dated 27.11.63, the Swedish King Gustav Adolf VI suggested a further examination of a piece from his collection.

5. R.J. Gettens, Freer Gallery of Art, Washington, 7.5.63. A schematic drawing of the construction by E.W. FitzHugh was included.

6. A.R. Sollars, Department of Materials, College of Aeronautics, Cranfield, Bletchley, Buckinghamshire, 17.6.63. It is clear from the letter that Sollars must have examined several samples for Garner. It is possible that the discussion was about one of Garner’s cross sections (1963) without it being referred to specifically. There is a photograph in that article [Fig. 4, “magnification about x10”] which bears a reference to A.R. Sollars of Cranfield (“magnification x10”).

7. For example, H. Trubner of the Royal Ontario Museum, University of Toronto, sent him a sample of a pre-Han or Le-yang piece.

8. P.H. Pleisch, University of Keble, 29.9.85.

9. On 23.6.64 from Inv. 53.8 of the Freer Gallery of Art, Washington, D.C.


11. V.A. Moss requests an answer to this in his letter of 18.4.67.

12. In a letter to J. Needham on 29.12.66 and in correspondence with his nephew V.A. Moss on 15.10.69 and 20.10.72.

13. In letters to J.S. Mills, National Gallery, London (answered on 11.7.70) and V.A. Moss (answered on 6.5.71) and in debate with R.C.A. Røtterlænder of the Labor für Bernsteinforschung, Bonn, on suggested procedures using infrared spectroscopy and field ionization mass spectrometry.

14. In response to his own suggestion from his nephew V.A. Moss, Garner writes on 20.10.72: “I will alter ‘urushic acid’ to ‘urushi’. Should I not also alter ‘acids’ . . . . . to ‘components’?”

15. Thus on 11.12.69 Garner receives from Sir G. Taylor, Director of the Royal Botanical Gardens, Kew, Richmond, Surrey, the information that Rhus vernicifera DC is a synonym of Rhus verniciflua Stokes; the latter is the correct name for this species.”


17. In a letter to R.J. Gettens of 8.5.66, Garner writes: “Among the known (Han) lacquer pieces, I would say that less than 5% have fabric.” However, Gettens had informed him long before that (2.3.64) that he had found no fabric supports in the pieces studied from the Freer Gallery.

18. The cross section bears the note “inset C. strong black layer,” which may refer to the heavily applied “black guide line” (Garner 1963). Unfortunately, the origin of the sample and the name of the preparer are unknown. An additional cross section of a “16th C.” piece should also be mentioned here.


20. One reason for this may be that urushi is not used as a binding agent in the West, yet the analysis of binding agents has been developed largely in the West.

21. J.S. Mills to Garner, 11.7.70.

22. These results may rest on the observation that earlier lacquers differ radically from later ones, an observation that has never been satisfactorily explained (Burmester 1983b).

23. High-resolution mass spectrometry was carried out on the samples discussed here, nos. 1, 2, 4, 5, 7–9, 11, 12, 14–16, 18–24, 28 on two pieces of Chinese carved lacquerware dated 1566 (DA 20.8193) and second half, eighteenth century (DA 20.8048K), on a Japanese zoko bowl of the second half of the nineteenth century (9.645B) and on three recent examples from Japan and Thailand. The three additional pieces were also from the collection of the Linden-Museum in Stuttgart. The high-resolution mass spectra of these samples usually showed high intensities for the following masses (in order of their calculated C13H4O3 compositions): C13H25O, C13H26O, C13H27O, C13H29O, C13H31O, C13H33O, C13H35O, C13H37O, C13H39O, C13H41O, C13H43O, C13H45O, C13H47O, C13H49O, C13H51O, C13H53O, C13H55O, C13H57O, C13H59O, C13H61O, C13H63O, C13H65O, C13H67O, C13H69O, C13H71O.

24. Depending on their date, the pieces examined demonstrated the following high-intensity peaks: C13H25O for Yuan (Y) and Ming (M); C13H25 for Zhou (Z) and Qing (O); C13H20 for M and O; C13H25 for Z; O and modern lacquers (ma); C13H25O, Q, C13H25O, M; Q, C13H25O, Y, M, C13H25O late M and so on, C13H25O Han (H) to: ma; C13H25O Y, M, and early Q; C13H25O ma; C13H25O late Y to; ma; C13H25O Z, H, C13H25O Y to; ma; C13H25O Z, H, C13H25O Z to; ma; C13H25O late M and O; C13H25O Z; C13H25O O and ma; C13H25O Z, C13H25O O and ma; C13H25O late Ma to; ma; C13H25O Z and ma; C13H25O ma; C13H25O ma; C13H25O Z and C13H25O O. It should be made clear that this note and the previous one are intended merely to convey experimental results, not to deliver broad conclusions.

25. The equipment and parameters used in the experiments conducted here were: Laser Microspectral Analyzer (IMA 10 Jenoptik Jen) with Quartz Spectrograph DQ24, O-switch-cuvette 2, diaphragm 1(2), magnification 40/16, lamp voltage 0.9V, battery 1, spark voltage 4KV, induction 125MHz, delay time 400μsec, electrode gap 1.6 mm, electrode-to-sample gap 1.2 mm; O24: width of slit 10μc, slit height 1 mm, aperture 1.6.

26. Zeiss photomicroscope III with dark field illuminator. Film: Kodak Ektachrome, artificial light, 160 ASA.

27. Philips PW 1700 automatic powder diffraction system. Cu-fine-focus tube 40KV/30mA.

28. The high proportion of amorphous binding agent urushi proved to be a problem here, in that it produced a very high background.

29. Lacquer bands, according to Garner’s definition (1963) are made up of several lacquer layers which have the same pigmentation and therefore the same color.
30. An analytical review of the corresponding layers of no. 2 shows low intensities of Ca3, and Mg1, (for notation see Appendix); of no. 4, cinnabar (HgS, see below) contaminated from the ornamental layer73: Ca3, Hg2, and Mg1, and, contaminated in the same fashion, in no. 10. Ca3, Mg3, Fe3, Ba2, Hg2 and Si. As explained in detail below, all elements except manganese can be traced back to the application of natural cinnabar, originating (as in no. 4) in the ornamental zone.

31. In individual cases it was extremely difficult to direct the laser beam onto the selected lacquer layer because the microscope used for selection did not permit color observation.

32. Mänchen-Helfen (1937b) brings to our attention a section of the Cho-kung lu of Tao Tsung-yi (A.D. 1365) which is concerned with the ground:

"The lacquer workers buy the objects to be decorated from the turners. They are made of thin, soft pieces of wood bound by glue. First the joints are smoothed and any gaps filled with a mixture of natural lacquer and glue, called shaé-t'ang. . . . They cover the object with a layer of lacquer. On top of this they place a linen cloth. The first layer of ash is then applied. In all, three layers of ash are used, mixtures of ash, powdered brick and lacquer and ever finer linen. Each layer, as soon as it is dry, is polished with sand leather [like our glass paper]. For cheaper products a mixture of pig's blood and rice paste is used and, instead of linen, hemp. On top of the last layer of ash, there is another layer of lacquer—tsao ch'". . . and in this way the object has been well primed. When red lacquer is used, there is no tsao ch'."

The question must be raised, both here and for other sources, as to whether the translation is accurate (e.g. linen and hemp). Garner spent years pondering this issue as can be seen by the bibliography of his book (1978).

33. The increased thickness of the layer naturally extends the drying period. In reference to this, Garner (1978) quotes from the Cho-kung lu of Tao Tsung-yi (A.D. 1366):

"...referred to the meticulous care with which the ground work was done and each layer polished before the next was applied. It mentions that several months elapsed between the preparation of the base and the application of the first coloured layer."

In comparison, the drying time for a lacquer layer in the ornamental zone is between four and five days.

34. Mänchen-Helfen (1937b) translates from the Ko-ku-yao-lun of Ts'ai Chao of A.D. 1388 (edited 1459):

"... the objects produced lately under Yüan in Yang-hui and Si-t'ang. Kia-hing-fu have many layers and are carved in strong relief, but the fat content of the lacquer is too low. There are many well-worked pieces but the lacquer flakes off very easily on those with yellow ground."

This is further evidence that the adhesion is weakened between the yellow ground and the ornamental zone. This concept is supported by a comment about a Chinese gùili lacquer bowl (fifteenth-sixteenth century) by Gabbart (1978):

"the yellow lacquer layers sometimes seem to have the effect of raising the ornamented sections."

However, this raising of the ornamental sections was due not to the yellow layers but to the movement of the wood with respect to the stability of the ornamental zone.

35. In no. 11 (Fig. 18) as (Sn), Ca3, As3, Mg3, Si, Fe3 and (Si), Ca3, As3, Mg3, Al, Si, Fe1; no. 14 (Fig. 20, 21) as Ca3, As3, Mg3; no. 15 (Fig. 23, 24) as As3, Hg3, Ca3, no. 21 (Fig. 25) as Ca3, Mg3, Fe3, Al, Si, Mn, Hg3, Al; no. 22 (Fig. 31, 32) as Ca3, As3, Mg3, Si, Fe3, Hg3, no. 23 (Fig. 34) as As3, Ca3, Mg3, and in no. 25 (Fig. 39) as Ca3, Mg3, Si, Fe3, Mn, Hg3, Al; no. 10 (Fig. 15) as Ca3, Ba2, Mg3, Fe3, Mn, Si, Mn; and no. 12 as Ca3, Mg3, Hg3.

36. Garner (1983) explains evidence of mercury in the yellow ground as contamination from the ornamental zone above, but this interpretation can now be excluded.

37. However, it can be assumed that emperium, like other pigments (especially cinnabar), was available from other Chinese provinces (Yenetsuwa 1956) and was imported from abroad.

38. Movement of wood refers to dimensional change arising from a variation in moisture content.

39. On no. 4 (Fig. 9; HgS, low intensity spectrum); no. 6: Ba2, Ca3, Cr3, Hg3; no. 8 (Figs. 12, 13): Ca3, Hg3, Fe3, Mg3, Mn3; no. 10 (Fig. 15): Ca3, Ba2, Mg3, Fe3, Mg3, Si, Mn; no. 12 as Ca3, Mg3, Hg3.

40. No. 15 (Fig. 23): Hg3, Ca3, Fe3, Mg3, Al, Si, no. 16: Hg3, Ca3, Fe3, Mg3, Si, no. 17: twice Hg3, Ca3, Mg3; no. 18: Hg3, Ca3, Mg3, Mn3, Si, Fe3, and Hg3, Ca3, Mn3, Mg3, Fe3, Mn, Hg3, no. 19 (Figs. 26, 277): Hg3, Ca3, Mn3, Fe3, Hg3, Ca3, Mn3, Mg3, Fe3, Hg3, Mn3, Fe3, Mn, Hg3; and finally Fe3, Hg3, Ca3, Mn3, Hg3, Fe3; no. 20: Ca3, Hg3, Mg3, Si, Fe3; no. 21 (Fig. 29): Hg3, Ca3, Mn3, Si, Fe3, Mg3, Mn3, Mg3, Mn3, Ca2, Hg3, Mg3, Mn3, Mg3, Mn3, As3, Mn3, no. 22 (Figs. 31, 32): Hg3, Ca3, Mg3, Ba2, Mn3, As3, Mn3, Ca2, Hg3, Ba2, Mn3, Mn3, Ca2, Hg3, Mn3, Mn3, Ca2, Hg3, Mn3, Mn3, Ca2, Hg3, Mn3, Mn3, Ca2, Hg3.

41. Because of the low contamination in the red of a carved lacquer object from the fifteenth century, Garner (1963) concluded that vermilion had been used. In view of the experience gained here and a study of the original analysis, these results should not be interpreted in this way; rather they are a clear indication of the presence of natural cinnabar. Garner's reference is to a source not available to the author and which refers to the use of dry-process vermilion since the fourth century B.C. (Read 1938).

42. In no. 14 (Figs. 19–21) with Ca3, Fe3, Mg3; in no. 19 (Figs. 26, 27) with Fe3, Hg3, Al3, Si3, Ca3, Mn3, Ti2, Mg3; and in no. 26 with Fe3, Hg3, Mg3, Mn3.

43. No. 22 (Figs. 31, 32): Ca3, Fe3, Mg3, As3, Si, Mn3; no. 23 (Fig. 34): Fe3, As3, Ca3, Hg3, Mg3.

44. No. 1 (Fig. 5): Fe3, Hg3, Mg3, Al3, Ca3, Ti2, Mn3; no. 8 (Fig. 11): Hg3, Si3, Ca3, Mn3, Fe3, Ba2, Mn3, Al3, Ti2, Fe3; no. 12: Ca3, Mn3, Hg3; and no. 19 (Figs. 26, 27): Ca3, Hg3, As3, Mn3, Si, Mn3, Fe3.

45. No. 14 (Figs. 20, 21): Ca3, Mg3, and Ca3, Mg3 as well as Ca3, no. 24 (Fig. 38): Ba2, Mn3, Si, Hg3, Ca3, Mg3, Si, Fe3 (contaminated); no. 25 (Fig. 39): Si3, Ca3, Hg3, Mg3, Fe3, As3, Hg3, as well as Hg3, Ca3, As3, and Ca3, Hg3.

46. The list of evidence of mercury in black layers can be expanded to include a piece of the Jiaging era (Linden-Museum, Stuttgart, DA 20 799L; Burmester, Brandt 1982) which was not included in the series of lacquergen described in detail here.
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