A Technical Study of Inlaid Eastern Zhou Bronzes in the British Museum Focusing on a Unique Figure of a Leaping Feline

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A bronze figure of a leaping feline (1883,1020.5) with gold and silver decoration has been dated to either the Eastern Zhou period (770–221 BC) or the Song dynasty (960–1279 AD). All arguments that support or oppose either attribution were based on stylistic features. In this paper a technical examination using a wide variety of analytical techniques was carried out to attempt to establish its date more scientifically. The investigation showed that the feline was made by casting the hollow body and legs then separately casting on the hollow head, or vice versa. The solid tail was also cast separately but was attached with soft solder and is probably a replacement. The 'spacers' in the wall of all the hollow parts appear to be non-metallic or holes where spacers have been removed. This evidence suggests that piece mould casting was probably the method of manufacture. The figure is decorated with silver inlays set into cut channels lined with a fine-grained filler. The gold decoration is fire gilding, which was applied after the silver inlays were in place.

The alloy composition and likely use of the piece mould casting method suggests that it is probably an Eastern Zhou product with later replacement of the tail and some repairs. If it had been made in the Song dynasty, the lost-wax method could have been used for this figural object. This hypothesis is, however, difficult to prove, as casting techniques and surface decoration of Song bronzes have not been studied in sufficient depth.

KEY WORDS: Eastern Zhou; Chinese bronzes; inlay; gold; silver.

1. Introduction

Bronzes with inlay decoration were popular from the Eastern Zhou period (770–221 BC), especially from the Warring States period (c. 475–221 BC), including inlaid animal figures used as table legs and corner fittings. A unique bronze figure of a leaping feline inlaid with gold, silver and copper in the British Museum collection (registration no. 1883,1020.5, Fig. 1), which may have supported a tray on its front paws, was tentatively dated to the late Eastern Zhou period, 4th to 3rd century BC, based on the style of its decoration, and so labelled in the British Museum’s Joseph E. Hotung Gallery. However, some scholars disagree with this dating and believe it could be a Song dynasty (960–1279 AD) product.1,2) All arguments, either supporting or opposing the Eastern Zhou date, were based on stylistic features rather than technical aspects.

Some technical aspects of this piece were studied in the 1980s and it was found that the alloy (analysed using atomic absorption spectrophotometry [AAS] on a drilled sample from the right foot) is a low tin bronze with low levels of all the other elements looked for, and that the tail was attached with soft solder; solder was also found on the front paws and the repair to the left knee was made in lead. The casting technology and inlay techniques were not studied, although mercury was noted in the gold. The green patina was suspected to be artificial, as only the sample from the back of the proper right hind leg produced an XRD pattern characteristic of a well-formed crystalline material and because of the unnaturally smooth and evenly coloured patina of the body.3) In this paper an in-depth scientific investigation was carried out in the hope of clarifying its date of manufacture.

This object is unique and no identical object is known to the authors from excavation or other collections. In order to understand the manufacture techniques for the feline, three other objects with gold and silver decoration (registration nos 1934,0216.1-3) were also studied here. In addition, because technical studies of inlaid Chinese bronzes have rarely been reported (despite some studies on their stylistic and decorative aspects), eight inlaid belt hooks of the Eastern Zhou to Han periods were chosen from the Museum collection for examination of their inlays.

2. Experimental

Surface examination was carried out using a Leica binocular microscope. X-radiography was used to examine the construction of the object and was undertaken using a Sietert...
DS1 X-ray tube with exposure conditions of 130–180 kV for 50 mA minute. Surface patina was identified by X-ray diffraction (XRD) using a Philips PW1012/90 Debye-Scherrer camera equipped with Cu Kα radiation. The sample was run at 40 kV, 15 mA for 16 hours. Diffraction lines were identified by matching with the ICDD database.

Compositional analysis of the metal was carried out using an Artax μXRF spectrometer with a molybdenum target X-ray tube rated up to 40 W and operated at 50 kV and 500 μA with a counting time of 200 seconds. The areas analysed were cleaned by abrading using a scalpel and silicon carbide paper prior to analysis to remove corrosion products and dirt.

Gold and silver inlays were studied using small cross-sections taken from damaged inlays on the belt hooks. A micro-scale section of the gold decoration on the feline was taken from a broken area for detailed study of its composition and microstructure. The samples were mounted in Epoxy resin, polished to 1 μm and analysed by scanning electron microscopy coupled with energy dispersive X-ray spectrometry (SEM-EDX) using a Hitachi S-3700N Variable Pressure SEM with an Oxford INCA Energy system. The analyses were run at an accelerating voltage of 20 kV at low vacuum (50 Pa) with a working distance of 10 mm.

3. Results and Discussion

3.1. The Green Patina on the Surface

Small samples of the surface green patina were taken from several places on the object and analysed by SEM-EDX. All but the dark green patina on the tail showed similar results; they contained copper, tin and phosphorus with silicon and aluminium. The dark green patina on the tail does not contain phosphorus and tin, which adds to the evidence that the tail is a replacement. A sample of patina taken from the back of the proper-right hind leg, which produced a well-formed crystalline XRD pattern, was identified as a mixture of cuprite (Cu2O), cassiterite (SnO2) and possibly other materials, because there are a few unidentified lines. However the sample taken from the body of the feline indicated a poorly crystalline material.

3.2. Manufacture

The X-radiographs (Fig. 2) suggest that the feline consists of three separately-made components: the hollow body with
legs, the hollow head and the solid tail. The metal walls of the hollow components are relatively thin. The four paws are all solid and were probably cast with the body. The hollow body and head can be seen to be separated by a wall of metal across the base of the neck (paler area). It was not possible to determine the composition of this metal join analytically, as it is covered with patina and cannot be accessed by the XRF equipment due to its curved shape. However, it is unlikely to be soft solder as a tin-lead alloy would not develop the same patina as the bronze and would be expected to be visually detectable from surface inspection, which is not the case. The join of the body and the head was probably formed by ‘lock-on’ casting,\(^4\) achieved by inserting the pre-cast head into the mould for the body or by building the mould for the head onto the pre-cast body. The casting has been very carefully finished, leaving no trace of mould join marks so it is not possible to prove what form the mould took. Su\(^5\) in his study of a rectangular bronze stand with four dragons and four phoenixes from the middle Warring States-period tomb of Cuo at Sanji, Pingshan, Hebei suggested that the body of the dragons was moulded in three pieces, and this may also be the case for the British Museum feline, with one part for the curved back and one for each side at the front. Animal-shaped bronze objects similar to (but not identical to) the leaping feline were also said to have been cast by using the piece-mould method but no detailed technical study of these pieces has been found.\(^5\)\(^7\)

To confirm what was suspected about the feline’s construction from X-radiography, compositional analysis using XRF was carried out on small areas (approximately 1 mm in diameter) at different places: the body, the head and the front and back paws where surface patina is missing. Because the analysis is of the surface and since minimal preparation was carried out to remove surface corrosion, it may not be fully quantitative. Nevertheless, it was expected that it would be possible to determine the difference or similarity between the areas analysed. The detection limits for each element vary, but are typically \(0.1–0.2\%\). The relative precision (reproducibility) is \(c. 1–2\%\) for copper and \(c. 10–30\%\) for the other elements quoted, deteriorating to \(50\%\) as their detection limits are approached. The XRF results, together with the previous AAS analysis, are presented in Table 1. The alloy compositions of the body and the paws are very close, within the experimental error, confirming that they are the same casting. The body contains significantly less lead (\(c. 0.4\%)\) than the head (\(c. 2\%). The analyses carried out on two areas on the head gave similar results, indicating that this higher lead content (than in the body as well as the legs and paws) is not due to segregation of lead but represents a real difference in alloy composition between the body and the head, thus suggesting that the head is a separate casting. Despite the presence of the repair on the left leg, the left hind paw appears to be the original, as its alloy composition is reasonably similar to the right hind paw. The alloy compositions of both the body and the head fall within the range for the inlaid Zhou bronzes examined here (Table 2). Later Chinese bronzes of Song to Qing dynasties often contain higher levels of iron and zinc.\(^8\)

A large number of regularly-positioned dark features, initially interpreted as spacers, were found by X-radiography in the wall of all the hollow-cast parts and there is no evidence for an internal armature. Their very dark appearance in the X-radiographs indicates that they are of a much less dense material than the alloy of the feline. The squarish ‘spacers’ measure 2–4 mm wide and some are recessed below the level of the surface. Most of these features are covered with inlays making it difficult to examine them (Figs. 3 and 4). However, removal of the surface crust of dirt and corrosion over one of these features suggests that it is non-metallic, which would explain the dark appearance in the X-radiographs. XRF analysis on those which could be accessed by the beam showed the presence of iron. For example below the left shoulder (which is partly uncovered by the inlay) the main element detected was copper with a small amount of iron; however, even under magnification, no metal could be seen. Non-metallic spacers have been reported in the Xing Hou gui (registration number 1936,1118.2), an early Western Zhou period vessel.\(^9\) The

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**Table 1.** XRF analysis (normalised results; wt.\%) of the feline (*AAS analysis*) (Locations of XRF analyses are indicated by arrows and number in Fig. 1).

| Area analysed       | Cu  | Sn  | Pb  | Fe  | As  | Ag  | Au  | Co  | Ni  | Sb  | Zn  | Total |
|---------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Right hind paw*     | 91.2| 2.5 | 0.34| 0.15| 0.05| 0.07| 0.03| 0.03| 0.15| 0.04| 0.03| 94.59 |
| 1. Right hind paw   | 96.0| 3.2 | 0.4 | tr. |     |     |     |     |     |     |     | 0.1   |
| 2. Left hind paw    | 94.3| 4.3 | 0.7 | 0.1 |     |     |     |     |     |     |     | 0.2   |
| 3. Body             | 96.9| 2.4 | 0.4 | tr. |     |     |     |     |     |     |     | 0.1   |
| 4. Left front paw   | 96.1| 3.0 | 0.5 |     |     |     |     |     |     |     |     | 0.2   |
| 5. Head             | 95.7| 2.4 | 1.8 | tr. |     |     |     |     |     |     |     | 0.1   |
| 6. Head             | 94.5| 3.4 | 1.8 | 0.1 |     |     |     |     |     |     |     | 0.1   |
| 7. Tail             | 90.4| 0.8 | 6.4 | 0.3 |     |     |     |     |     |     | 1.7   |

**Notes**

AAS is a more sensitive technique than XRF, allowing low levels of a greater number of elements to be quoted for the analysis of the right hind paw; tr. denotes that an element was present below 0.1% but not quantifiable using XRF; blank entries denote that an element was not detected, *i.e.* peaks were not observed in a spectrum, and not present above the detection limit for XRF.
fact that most of the ‘spacers’ seen in the X-radiographs appear at the surface as recesses suggests that they could be holes (but covered with inlays in most cases), which are now filled with dust from surface burnishing and/or other materials. The copper and iron detected in these areas may be from corrosion products and clay core material. Small holes have also been recently observed on an Eastern Zhou crossbow holder (1934,0216.1) and non-metallic spacers (which could be holes covered by dirt) in another Eastern Zhou crossbow holder (1934,0216.2) were revealed in X-radiographs.

Spacers were used to keep the mould and core separate during piece-mould casting, the main technique used in the ‘Chinese Bronze Age’, including the Eastern Zhou period. However, such spacers are not easily seen on the surface of the casting. In comparison, the lost-wax method has generally been believed to have emerged later in China, in the transition between the Western Zhou and the Spring and Autumn period (770–475 BC)\(^{10}\) but recent studies by Zhou Weirong \textit{et al.} \(^{11}\) argued that the lost-wax method may not

\textbf{Table 2.} Results of XRF and SEM-EDX* analysis of inlaid belt hooks and three other objects (1934,0216.1-3).

| BM Reg. No | Area analysed | Cu  | Sn  | Pb  | Ag  | Au  | Inlay thickness (μm) | Channels cut | Filler used |
|------------|---------------|-----|-----|-----|-----|-----|----------------------|--------------|------------|
| 1932,1014.14 | Metal         | 14.1| 6.2 | 78.4|     |     |                      |              |            |
|            | Silver inlay* | 0.4 | 99.1| 50  |     |     |                      | yes          | yes        |
| 1932,1014.15 | Metal         | 38.5| 1.9 | 59.2|     |     |                      |              |            |
|            | Silver inlay* | 0.6 | 98.5| 90  |     |     |                      | yes          | yes        |
| 1932,1215.33 | Metal         | 92.7| 5.3 | 1.3 |     |     |                      |              |            |
|            | Silver overlay* | 0.4 | 98.0| 200 |     |     |                      | unclear      | yes        |
|            | Silver inlay on button | 1.5 | 97.8| 0.5 |     |     |                      |              |            |
|            | Gold decor-smooth* | 1.2 | 97.2| 10–16|     |     |                      | no           | none       |
|            | Gold decor-rough* | 18.2| 79.0| 10–16|     |     |                      | no           |            |
| 1936,1118.118 | Metal      | 98.7| 0.9 | 0.2 |     |     |                      |              |            |
|            | Gold inlay* | 0.4 | 90  | 89.6| 40–50|     |                      | unclear      |            |
|            | Gem inlay   |     |     |     |     |     |                      | beeswax      |            |
| 1936,1118.122 | Metal      | 94.1| 3.0 | 2.0 |     |     |                      |              |            |
|            | Silver sheet at end | 21.7| 74.2| 0.3 |     |     |                      |              |            |
|            | Spiral silver inlay* | 0.6 | 98.6| 40  | yes | none     |                      |              |            |
| 1936,1118.126 | Metal      | 72.4| 1.0 | 26.3|     |     |                      |              |            |
|            | Silver inlay | 1.8 | 97.1| 0.9 |     |     |                      | unclear      |            |
| 1947,0712.354 | Metal      | 84.1| 3.5 | 10.6|     |     |                      |              |            |
|            | Gold inlay  | 2.3 | 1.6 | 96.1|     |     |                      | yes          | none       |
| 1947,0712.360 | Metal      | 91.7| 5.3 | 1.6 |     |     |                      |              |            |
|            | Gold strip inlay* | 0.2 | 10.2| 88.2| 130 | yes | none     |                      |              |            |
|            | Gold sheet inlay* | 0.4 | 9.7 | 89.7| 70  | unclear |                      | unclear      |            |
|            | Silver inlay | 5.7 | 93.4| 0.8 |     |     |                      | unclear      |            |
| 1934,0216.1 | Metal        | 94.4| 3.1 | 1.9 |     |     |                      |              |            |
|            | Silver inlay | 0.9 | 0.2 | 98.8| 0.2 |     |                      |              |            |
|            | Gold inlay  | 0.4 | 2.9 | 96.8|     |     |                      |              |            |
| 1934,0216.2 | Metal        | 95.0| 2.5 | 1.8 |     |     |                      |              |            |
|            | Silver inlay | 12.2| 87.0| 0.1 |     |     |                      |              |            |
|            | Gold inlay  | 0.6 | 2.9 | 96.5|     |     |                      |              |            |
| 1934,0216.3 | Metal        | 94.7| 5.0 | 0.1 |     |     |                      |              |            |
|            | Silver inlay | 1.1 | 0.3 | 98.4| 0.2 |     |                      |              |            |
|            | Gold inlay  | 0.3 | 10.2| 89.5|     |     |                      |              |            |
have been in use until the Northern Dynasties period (386–581). The lost-wax method was widely used in the Song dynasty, although piece-mould casting was also used at that time. In lost-wax castings the core is held in place by pins (chaplets), which are pushed through the wall of the wax model into the core. They are usually smaller in diameter than spacers and more readily visible on the surface. Chaplets can be of a different metal to the casting or even non-metallic (for example, wooden sticks) and may be removed or be lost during manufacture, leaving a hole, as seen on African bronzes. The lost-wax method is arguably an easier method to model sinuous forms such as this feline sculpture, and if the lost-wax method had been used in this case then it is likely that the body and head would have been modelled and cast in one piece. Even if it was made by lost-wax casting, an Eastern Zhou date would not be ruled out by some scholars. Mould joint marks, another feature of piece-mould casting, were not observed on this object, but they could have been removed by finishing prior to the application of surface inlay decoration. The evidence from this study is inconclusive on this point.

X-radiography (Fig. 2) revealed that the pads of the paws were denser and they were found to be coated with lead (Pb) and tin (Sn), indicating the use of soft solder. Arsenic (As) was detected at the junction between the front left leg and paw, but was not noted elsewhere. This may indicate a more recent intervention, e.g. the application of an arsenical pigment to conceal damage.

The tail is a solid casting inserted into the body, as evidenced by the X-radiograph (Fig. 2). A low level of zinc was detected in the tail, the only area where zinc was detectable by XRF on the figure, which is unusual for Zhou bronzes. As mentioned earlier, the tail was attached with soft solder, also suggesting that the tail may not be original.

3.3. Silver Inlay

Channels for the silver inlay decoration were cut as grooves around the edge of the area to be inlaid, as evi-
enced by the tool mark present in the areas where the inlays are missing. Studies of the inlaid bronze belt hooks of the Eastern Zhou / Han period also showed cut channels for metal inlays. It has been suggested by Jacobsen\(^2\) that from the 4th century BC onwards designs receiving metal inlays were generally cut after casting.

A fine grained paste present underneath the silver inlays was found to contain mainly silicon, aluminium, calcium, magnesium and sodium by SEM-EDX analysis, a composition typical of clay materials. No organic material or glue was identified in the paste by Fourier transform infrared spectroscopy (FTIR). The same feature has been observed on silver inlays on some of the belt hooks (1932,1014. 14 & 15 and 1932,1215.33) studied. This paste probably acted as a filler to help hold the inlay in place and to make finishing the surface easier. Although scientific evidence of use of paste for holding metal inlays in place has not been found, the probable use of cement as an adhesive was reported for turquoise inlay.\(^4\) The feline’s claws were inlaid with silver but some are now missing. Small punched pits around the edges of the inlay area were used to key the edges of the inlay to the curved surface. It is not clear if this was an original feature or a later repair.

The sharp breaks in the silver inlay, the presence of material between the inlay and the metal substrate and the grooves for keying it indicate that the silver decoration, both in sheet and wire form, was applied mechanically. The sheet and wire silver inlays are separate pieces and were joined mechanically, as shown in Fig. 5. The wires are sandwiched between the split ends of the sheet and the joins are so well finished they can hardly be seen in some cases.

### 3.4. Gold Inlay

Where damaged, the gold inlay shows irregular missing patches (Fig. 6) rather than flaking at the ends or edges, which is more normal for metal inlays and is seen on the silver inlays here. Fractures observed in the gold inlay around the neck reflect the fractures in the bronze substrate caused by tension at the body-neck join. Channels were cut in the bronze for the silver inlays, but are not obvious for the gold inlay and thus it may be a slight misnomer to regard the gold as ‘inlaid’. The XRF analysis of the gold inlay surface detected the presence of mercury (Hg) in most of the areas analysed, which might indicate fire-gilding, or contamination from cinnabar in a burial context.

It has been reported that fire-gilding had been in use in the Warring States period (475–221 BC) by the late 4th century BC. The process of fire-gilding can be described as follows: gold amalgam (a mixture of gold and mercury) was applied to the cleaned metal surface, heated to 250–350°C for a few minutes causing much of the mercury to evaporate, and burnished to produce a smooth and firmly adherent layer of gold.\(^13\) In some cases, several layers of amalgam might be used and the last of which was burnished flush with the bronze surface.\(^2\)

In order to determine the nature of the ‘gold inlay’ and the level and distribution of mercury in the gold, a micro-scale section of the inlay was taken from a broken area (Fig. 6) with the curator’s permission, mounted in resin and polished for a detailed study using SEM-EDX. The gold is approximately 15 μm thick (which is similar to that of the gilding on an Eastern Zhou inlaid belt hook 1932,1215.33) (Table 2). It was found to contain 6–11 wt.% mercury, highest at the inner surface in contact with the metal and decreasing toward the outer surface. Studies of gold inlays on six Chinese bronze objects of the Eastern Zhou period showed that they are gold-silver alloys rather than pure gold (Table 2). The fact that the gold on the feline only contains gold and mercury indicates gilding rather than inlays. The presence of mercury could be due to either fire-gilding or leaf gilding using mercury as an adhesive. The gilding on the feline is too thick to be leaf but it could be foil (leaf is much thinner than foil). Though the mercury content is consistent with the characterised residual mercury content of 8–25% in the gold produced by fire-gilding,\(^13\) it is not possible to differentiate between leaf (foil) gilding and fire-gilding based merely on the mercury content.\(^14\) The porous and granular structure of the gold on the feline (Fig. 7) has the physical structure of fire-gilding.\(^14\) Furthermore, if it had been foil gilded with mercury, mercury should be con-

![Fig. 5. Wires (indicated by arrows) added between and at the end of the sheets to make a continuous silver inlay. (Online version in color.)](image)

![Fig. 6. A broken area of gold inlay, showing the location where a metallurgical sample of gold was taken (circled). (Online version in color.)](image)
Centralized at the interface between the gilding and the substrate. The presence of mercury throughout the thickness of the gilding with decreasing amounts toward the surface (as mentioned above) suggests that it is more likely to be fire-gilding and unlikely to be contamination from contact with cinnabar.

Mercury was detected in some of the silver inlays but it is thought to be contamination from the neighbouring gilding. It is not surprising that the silver was not applied as an amalgam as, unlike gold, pure silver amalgam does not adhere well to copper alloys. At least as early as the Han period, a method was developed of using gilding as a base for silver amalgam on copper alloys, but gold was always detectable by XRF analysis when that method of silvering was used.15)

The gilding on the feline is smooth and shiny. This could be the result of a high degree of surface finishing of the bronze prior to the application of gilding and inlays, or perhaps also of extensive burnishing of the gilding. The smooth edges to the gold decoration suggest that a stencil technique might have been used. A few small areas where the gold was not well finished were observed. A layered structure of different hue in an area on the right thigh (Fig. 8) and an unburnished area of gold on a curved surface on the back add to the evidence in support of fire-gilding. Anheuser13) argues that patches of unburnished gilding are the main evidence on which to differentiate fire gilding from leaf-gilding, which usually has straight edges.

In some places the gilding appears to overlap areas that have been interpreted as spacers. If the spacers are either of a non-metallic material or are now holes, how could the gilding adhere? These features covered by gilding are of a square shape and levelled (Fig. 9) rather than being recessed as they seem to be when under the silver inlays. One possible solution is that a sheet of metal could have been stuck over the spacers or holes prior to the application of gilding, which might fit the evidence seen in Fig. 9, but there is no analytical evidence for or against this theory.

No joins were found in the gold decoration, as would be expected for gilding. The gilding was applied after the silver inlays, as evidenced by the flow of gilding onto the silver.
inlays (Fig. 10). The single small ring of gold under the right shoulder is difficult to understand, as the silver and gold decorative patterns are symmetrical in other places.

4. Conclusions

The investigation showed that the leaping feline was made by casting the hollow body and legs, then separately casting on the hollow head, or vice versa. The hollow body and head are separated by a wall of metal across the base of the neck. The solid tail was also cast separately but attached with soft solder and is probably a replacement. The ‘spacers’ in the walls of all the hollow parts appear to be non-metallic or holes where spacers have been removed. The alloy composition and likely use of the piece-mould casting method suggests that it is probably an Eastern Zhou product, with later replacement of the tail and some repairs. If it had been made in the Song dynasty, the lost-wax method could have been expected to be used for this object. This hypothesis, however, is difficult to prove, as casting techniques and surface decoration of Song bronzes have not been studied in sufficient depth, and also because of the lack of comparable objects. It is hoped that this study will promote more technical studies on inlaid bronzes of the Eastern Zhou and Song periods, particularly inlaid animal figures from archaeological excavations, to provide further information which may lead to a solid conclusion on this feline sculpture in the future.

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