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A gold four-horse model chariot from the Oxus Treasure: a fine illustration of Achaemenid goldwork

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Summary This paper outlines the results of the first scientific study of a delicate gold model of a four-horse chariot complete with driver and passenger, found in a large hoard of gold and silver artefacts known as the Oxus Treasure. This treasure is one of the most important surviving assemblages of sumptuary metalwork from the period of the Achaemenid Empire. It consists of about 180 objects, dating mainly from the fifth and fourth century BC, plus a large number of coins. The present technological study builds on previous analyses of Achaemenid silver and gold pieces in the British Museum collection. Microscopic examination, X-radiography and scanning electron microscopy combined with energy dispersive X-ray analysis have revealed undocumented evidence for the skill of the Persian goldsmith in creating an intricate artefact produced using a variety of techniques, such as repoussé and chasing on gold sheets, granulation, wire twisting and hammering.

INTRODUCTION

This contribution outlines the results of the first scientific study of a delicate gold model of a four-horse chariot complete with driver and passenger (BM 1897,1231.7: ME 123908), found in a large hoard of gold and silver artefacts known as the Oxus Treasure. This treasure consists of around 180 gold and silver objects, including large numbers of personal ornaments and votive plaques, and a small number of other objects; in addition there are a great many coins, which are dispersed in different collections [1]. It dates from the period of the Achaemenid Empire, which lasted for over two centuries from the reign of Cyrus the Great (reigned 559–530 BC). At its greatest extent this empire stretched from Egypt and the Aegean to Afghanistan and the Indus Valley [2]. As such it is the most important surviving assemblage of gold and silver metalwork from the Achaemenid period yet to be discovered and contains a number of pieces that are so far unique. The collection is a significant component of the new Rahim Irvani Gallery for Ancient Iran, which opened in 2007. The current study was initiated when it was decided that this object should be included in the radio series *A History of the World in 100 Objects*, a collaboration between the British Museum and the BBC. It builds on a number of recent studies of Achaemenid gold and silver working, including other pieces in the same collection [3–9]. The object has now been examined in detail for the first time, to allow a better understanding of the manufacturing technology of the chariot. The chemical composition of the gold was analysed by X-ray fluorescence (XRF) and scanning electron microscopy with energy dispersive X-ray analysis (SEM-EDX), while the physical features of this artefact were characterized by a complementary investigation using X-radiography, optical microscopy and SEM. A wide variety of goldworking techniques was identified, along with ancient alterations and recent conservation and restoration treatments.

COLLECTION AND EXHIBITION HISTORY

The Oxus Treasure was bequeathed to the British Museum in 1897 by Sir Augustus Wollaston Franks, one of the Museum's greatest curators and benefactors of the nineteenth century [10]. Contemporary accounts make it clear that most of the collection was found over the space of three or four years between 1876 and 1880 at a site called Takht-i Kuwad on the north bank of the river Oxus (modern

Amu dar'ya), close to the confluence of the Vakhsh and Pyandzh, and the collection soon became known as the Oxus Treasure [11, 12].

The Oxus Treasure was first placed on public display in the British Museum in 1900/1901 in the Gold Ornament Room (beyond what is today the Greek and Roman Life Room). A previously unpublished photograph shows the gold chariot model displayed alongside the gold armlet, vessels and larger plaques and placed on top of a cloth-covered block within a standard nineteenth-century showcase, Figure 1. At this stage the objects had clearly not been restored. The collection was later moved to the Franks Room at one end of the King Edward VII Gallery, which opened in 1923. It remained there until 1932 when it was transferred to the former Department of Egyptian and Assyrian Antiquities when it was reported to the Museum's Trustees that the "gold objects of the Oxus Treasure have been remounted on a new fitting and exhibition arranged" as part of the Museum's first "exhibition of antiquities from Persia and Armenia" in what was numbered as Room 20 [13]. Thereafter the Oxus Treasure has remained on display, as an integral part of the subsequent gallery displays for pre-Islamic Iran, in special exhibitions within the Museum or on exceptional loans to other institutions.[1]

The chariot model has, therefore, become a very well-known piece of ancient Iranian craftsmanship, but this is the first detailed scientific analysis of this complex artefact.

DESCRIPTION

The remarkable gold model chariot, presented here with its four horses and two figures, is one of the most outstanding pieces in the Oxus Treasure, Figures 1 and 2. The object is relatively small, measuring *c.*19.5 cm long and between *c.*4.5 and 7.5 cm high, and weighs approximately 75 grammes.

This chariot is pulled by four horses and carries two figures, a driver and a seated passenger. The passenger wears a long-sleeved overcoat and a hood or cap, whereas the driver wears a belted tunic and soft cap [1; pp. xxvii–xli]. Both wear gold torcs, a common sign of status in the Achaemenid Empire judging by contemporary representations and written sources [1; p. xxxiii]. The left wheel displays eight spokes whereas the opposite wheel has nine; both wheels originally rotated freely. The back of the chariot cab is open but has a pair of looped handrails that were designed to assist mounting and dismounting on the original chariots. The front is decorated with the face and feathered headdress of the Egyptian dwarf-god Bes at the intersection of two incised bands, which probably represent diagonal bracing struts. Within Egypt, Bes was regarded as an apotropaic deity for households and particularly mothers and children. Within the Persian Empire, representations of Bes are commonly found on pendants, glyptic and other objects and although it is uncertain whether his original attributes were retained,

FIGURE 1. Part of the original display of the Oxus Treasure in the British Museum in 1900/1901, with the chariot model (BM 1897,1231.7) on the right of the showcase

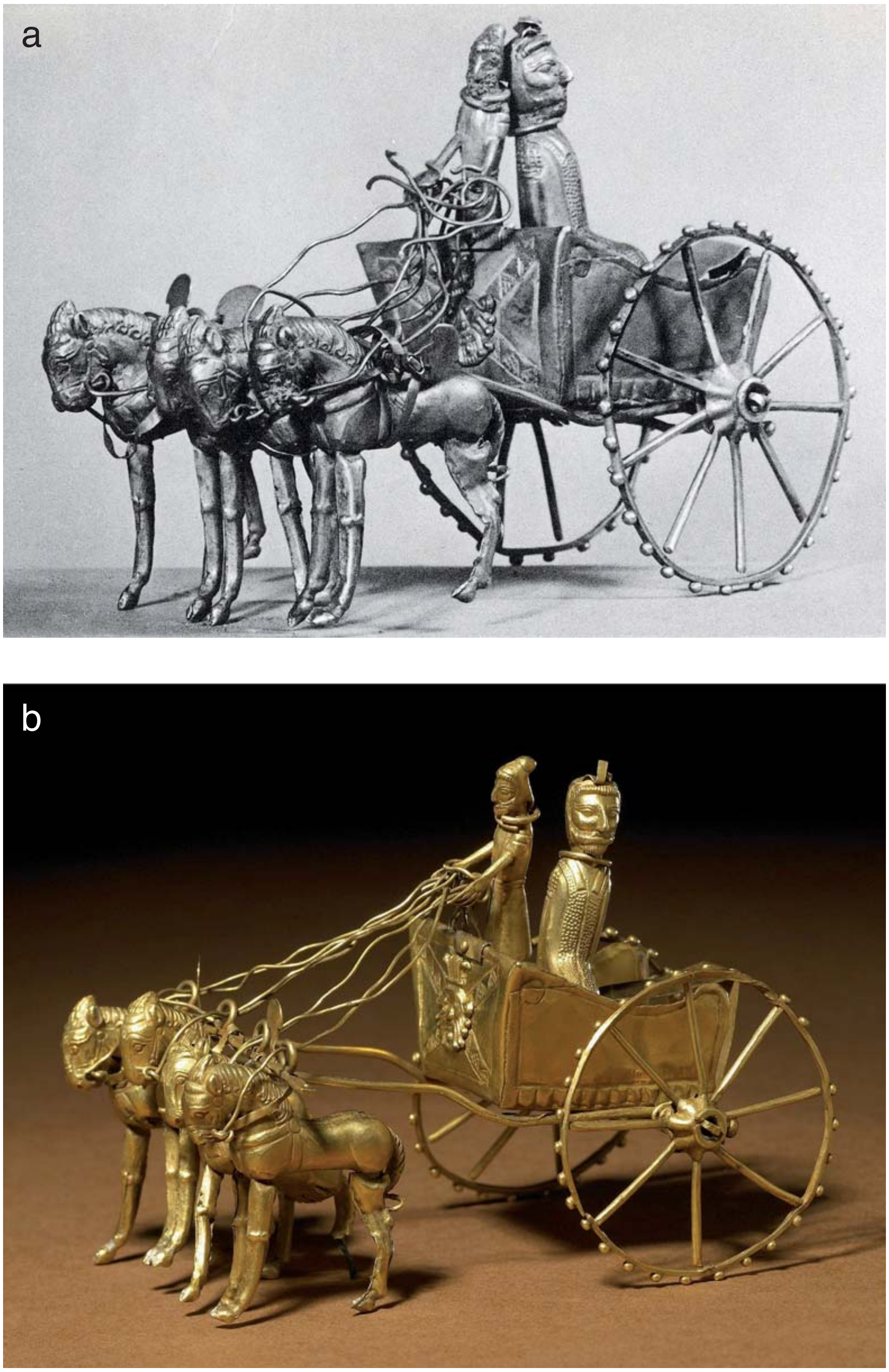

FIGURE 2. Images of the gold chariot model from the Oxus Treasure (length of chariot c.19.5 cm): (a) as first published in 1905 [1; Plate x]; and (b) as currently displayed

it is tempting to interpret his depiction on this chariot as evidence that it was intended for a child [14, 2; pp. 114, 133, 145 and 172]. A pair of shafts attaches the chariot to a four-bay yoke. The reins were guided through four individual metal loops, or terrets, which were also designed to prevent them from becoming entangled. Originally, a fan-shaped ornament representing a stylized plume was mounted between each terret but only two now remain, see [1; Plate IV]. These details, along with the profile of the chariot and the wheel construction, closely parallel those on contemporary Achaemenid depictions [2; pp. 70–71]. However, most of the latter show chariots viewed in profile and thus lack the perspective of the front or interior of the cab. The representation of Bes is absent from the second chariot model in the Oxus Treasure (BM 1897,1231.8: ME 132256), which only possesses a two-horse yoke, but otherwise shares the same features of a bench-like construction within the cab [1; p. xl, Figure 21 and Plate XLI, 2; p. 223]. To what extent these variations reflect differences between actual chariots is uncertain, yet the generally very close match between form and detail of Achaemenid representations, whether on sculptures or in miniature, suggests that these different details were indeed copied from reality.

METHODOLOGY

The physical characteristics and methods of manufacture of this artefact were studied using non-destructive analytical techniques, consisting of X-radiography, SEM-EDX and optical microscopy. Elemental analysis of the surface of the various parts of the chariot was carried out using XRF and the alloy composition was also analysed by SEM-EDX.

The scanning electron microscope used was a Hitachi S-3700N Variable Pressure SEM set to an acceleration voltage of 20 kV and a chamber pressure of 30 Pa. X-radio-graphy was carried out with a Siefert DS1 X-ray tube at 100 kV and an exposure of 10 mA for two minutes. The XRF instrument was a Brucker Artax spectrometer with a voltage of 50 kV and a current of 800 μA, using 0.65 and 0.2 mm collimators. Optical microscopy was carried out using a Leica Wild M8 stereomicroscope combined with a Leica DC 500 digital camera.

Surface analysis

When analysing gold artefacts it is important to consider surface depletion in copper and silver, which produces an apparent surface enrichment in gold. This depletion results either from 'pickling' of the gold by the craftsman during manufacture or from corrosion of the less noble metals – copper and silver – during burial. This well-known phenomenon, which affects both surface XRF and SEM-EDX analyses [15–17], creates a compositional gradient from the core to the surface of the object. While the 'surface XRF' analyses reported in Table 1 correspond to areas deeper than those penetrated by electrons in the SEM-EDX analyses, they do not reflect the core metal composition and give intermediate values between surface and core that may include a partial enrichment in gold. To determine the core composition, it was necessary to clean a small inconspicuous area, called 'sub-surface' by the authors, which was then analysed by EDX. This 'sub-surface' analysis was compared to an adjacent 'surface' EDX analysis to illustrate the degree of surface enrichment in gold by depletion in copper and silver, Table 2. The results are discussed and compared, therefore, in the light of the analytical technique used and the presumed relative depth of the area analysed. As seen in the following section, the analytical data clearly show the expected enrichment in gold at the surface of the object and the data in Table 2 and Figure 3 illustrate the depletion in copper and, at the outermost surface, silver. This depletion could result either from the metal having been deliberately 'pickled' in acid during manufacture, by corrosion during burial or a combination of the two factors. The pitted surface, which is characteristic of long-term depletion during burial, is plainly visible in the SEM images made at high magnification, Figure 4.

TABLE 1. X-ray fluorescence surface analysis of various components of the chariot

Area of analysis	Content (weight %)		
	Au	Ag	Cu
Bun of passenger	89.4	4.9	5.7
Top end of bench	92.3	4.6	3.2
Horse's head right	91.8	5.3	3.0
Horse's head right: seam	92.2	4.9	3.0
Right side of chariot	92.8	4.7	2.5
Left side of chariot	91.7	4.6	3.7
Back of bench	92.2	4.9	2.9
Floor sheet of chariot	92.2	5.3	2.5
Rivet at back of bench*	87.3	5.1	7.6
Granule on rim of right wheel	88.4	4.9	6.7
Wire on rim of right wheel	92.2	4.7	3.1
Spoke on right wheel	91.7	4.6	3.7
Spoke–rim joint on left wheel	89.9	4.6	5.6
Back of bench*	93.4	4.3	2.3
Central wire on right wheel	95.6	3.1	1.3
Right shaft	91.5	5.2	3.3
Right rein (top)	88.9	6.4	4.7
Centre fitting on right wheel	92.1	4.6	3.4
Head of driver	88.3	5.7	6.0
Wire rim of left wheel	91.2	5.0	3.8

Notes
All analyses were carried out with a 0.65 mm collimator, except those indicated with an *, for which a 0.2 mm collimator was used.
Precision was ±1–2% relative for gold and ±5–20% relative for silver and copper.

TABLE 2. SEM-EDX analyses of sub-surface core material and adjacent enriched surfaces on the upper side of the right edge of the yoke

Area of analysis	Sample	Content (weight%)		
		Au	Ag	Cu
Sub-surface core	1	88.1	4.8	7.2
Sub-surface core	2	88.3	5.0	6.7
Sub-surface core	3	88.4	4.5	7.1
Sub-surface core	4	88.4	4.7	6.8
Surface	5	96.9	1.5	1.6
Surface	6	97.8	1.2	1.0

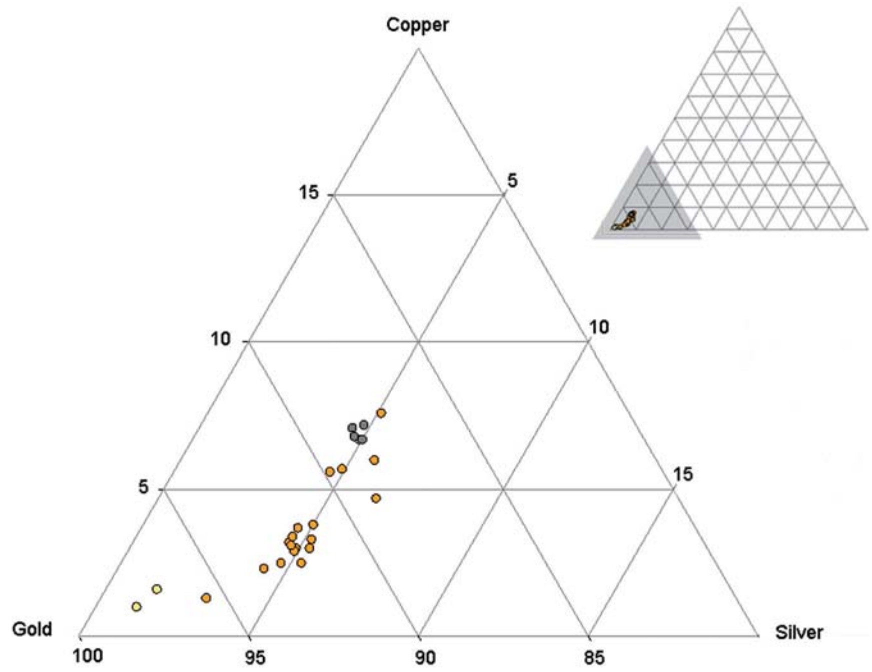

FIGURE 3. Ternary gold–silver–copper diagram displaying the data from XRF (orange circles) and SEM-EDX analyses of the surface (yellow circles) and 'sub-surface' (grey circles) compositions. These demonstrate the compositional gradient between the original alloy and the copper- and silver-depleted surface

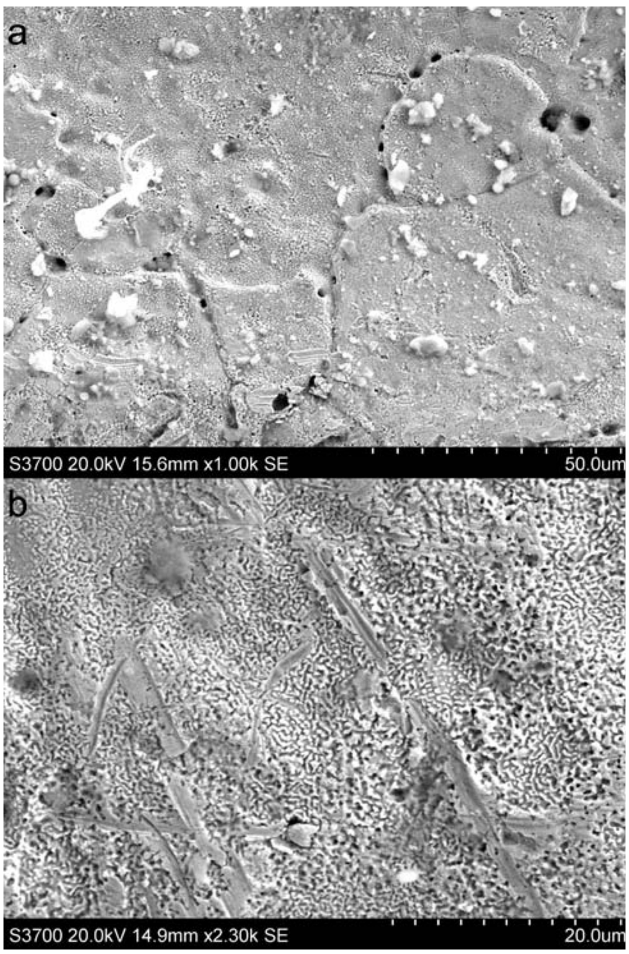

FIGURE 4. Backscattered electron images of a small area of one horse's head showing the porous and pitted structure and etched grain boundaries of the surface due to corrosion during burial: (a) at ×1000; and (b) at ×2300

MANUFACTURING TECHNOLOGY

Composition of the gold

Non-destructive surface XRF was carried out on 20 different components of the artefact in order to determine their relative compositions. The analytical results – which are expressed in weight% throughout – revealed that they contain between 87 and 96% of gold with an average of *c.*91%. The copper content ranges between 1 and 8% (4% average) and the silver content between 3 and 6% (5% average), Table 1. The variations in gold composition probably reflect different degrees of surface depletion in the areas analysed as no obvious pattern between specific compositions and types of components seemed to emerge from the XRF data.

For comparison, a surface area and an adjacent inconspicuous cleaned sub-surface area of the yoke were analysed by SEM-EDX. While the surface was composed of 98% gold, 1% copper and 1% silver, the sub-surface area comprised 88% gold, 7% copper and 5% silver, see Table 2 and Figure 3. Several of the surface areas analysed by XRF that are reported in Table 1, such as the rivet holding the bench at the back of the chariot, a bead on the rim of the right wheel and the top of the driver's head, show compositions comparable with the sub-surface analyses by SEM-EDX reported in Table 2 (Nos 1–4). The results suggest that these particular areas have suffered very little depletion compared to other components that show lower copper contents by XRF analysis in Table 1.

The metal used in the manufacture of this artefact is almost certainly native alluvial gold, which commonly

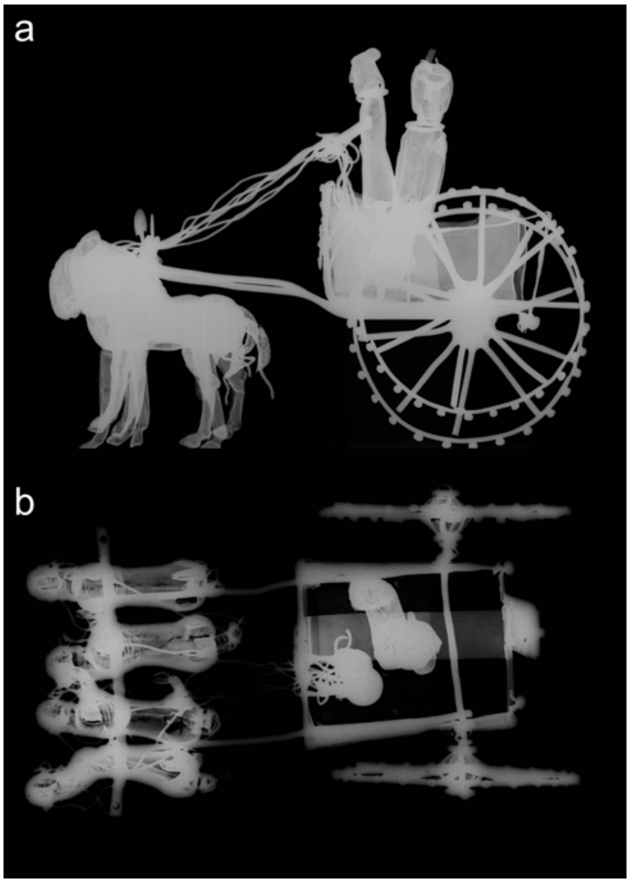

FIGURE 5. X-radiographs of the Oxus chariot: (a) from the side; and (b) from the top. The darker colour of the figures and the horses' bodies, legs and tails show that they are hollow, while the wires of the reins, shafts and axles are lighter showing they are made of solid gold, either block twisted or hammered

contains silver, to which copper has been added to produce the alloy identified here. The use of alluvial gold is inferred by the observation under the optical microscope of several platinum group element (PGE) inclusions in the metal on the horses. These are generally typical of gold from a placer deposit and, when found in artefacts, typically indicate the use of unrefined alluvial gold [18, 19]. Such inclusions have been noted previously in a study of many of the gold plaques from the Oxus Treasure [6].

The presence of silver in the alloy and the concentrations of this metal determined by XRF and EDX in the various components of the chariot strengthen the case of the use of an unrefined gold–silver alloy. However, previous analytical research suggested that the gold used in the plaques in the Oxus Treasure was alloyed with copper and "… probably silver before use and the use of refined gold cannot be ruled out" [6]. Gold refining is known to have been practised at Sardis on the western side of the Achaemenid Empire for at least a century before the likely date of this object [20], which suggests that refined gold could have been used for the manufacture of the objects in the Oxus Treasure. However, this refining process for gold would remove silver from the natural alloy; if refined gold was used for the artefacts in the Oxus Treasure, silver must have been reintroduced (as well as copper) to produce the ternary alloy identified here, a relatively laborious and inefficient process.

The copper content of alluvial gold is typically low, usually below 1% [20–23], but the sub-surface copper concentrations detected for this artefact are around 7%, Table 2. These levels are too high for the copper to have been part of the original natural gold–silver alloy and indicate an intentional addition of copper to the native gold alloy, which was common practice at the time. It is further worth noting that the copper content is slightly higher than that of silver (5%), for example in the sub-surface area on the yoke (Table 2): this is relatively infrequent, as most known ancient gold alloys show the opposite trend [24, 25].

Joining methods

This chariot displays a variety of joining techniques and mechanical joining is illustrated by riveting, folding and overlapping sheets, strips and wires. Due to the intricate geometry of the chariot and the sole use of non-invasive analytical techniques, it proved complicated to investigate and analyse all the joined areas and seams under the microscope and difficult, therefore, to identify the characteristic physical features of a soldered join, such as the meniscus joining granules to sheets or dendritic structures. Several joins, such as those on some of the spokes and granules on the wheels, show evidence that indicates the probable use of soldering as a joining technique on this object, but while only applying non-invasive analysis it is very difficult to point towards a specific soldering method – i.e. heating without solder, with hard solder or by copper salt diffusion bonding [26]. The absence of copper in the joining areas that were analysed does not necessarily imply that a hard solder or a copper salt was not used, as the copper may have been diluted by diffusion into the adjacent joined gold components during heating or depleted during burial, resulting in an alloy of similar composition to the joined parts.

Construction of the figures and horses

The two figures in the chariot are hollow and each was made of pieces of embossed gold sheet, Figures 5a and 6a. The seated passenger is larger than the driver, reinforcing his higher status, and both men are wearing torcs made of a single twisted gold wire. Backscattered electron images acquired in the SEM show that the figures and horses have seams running along their length (Figure 7), which indicate that they comprise two halves that were probably soldered together. Each half would have been worked separately in pre-shaped moulds by repoussé, while careful chasing was used for the final touches, such as the men's facial features and the horses' heads and manes. The coat

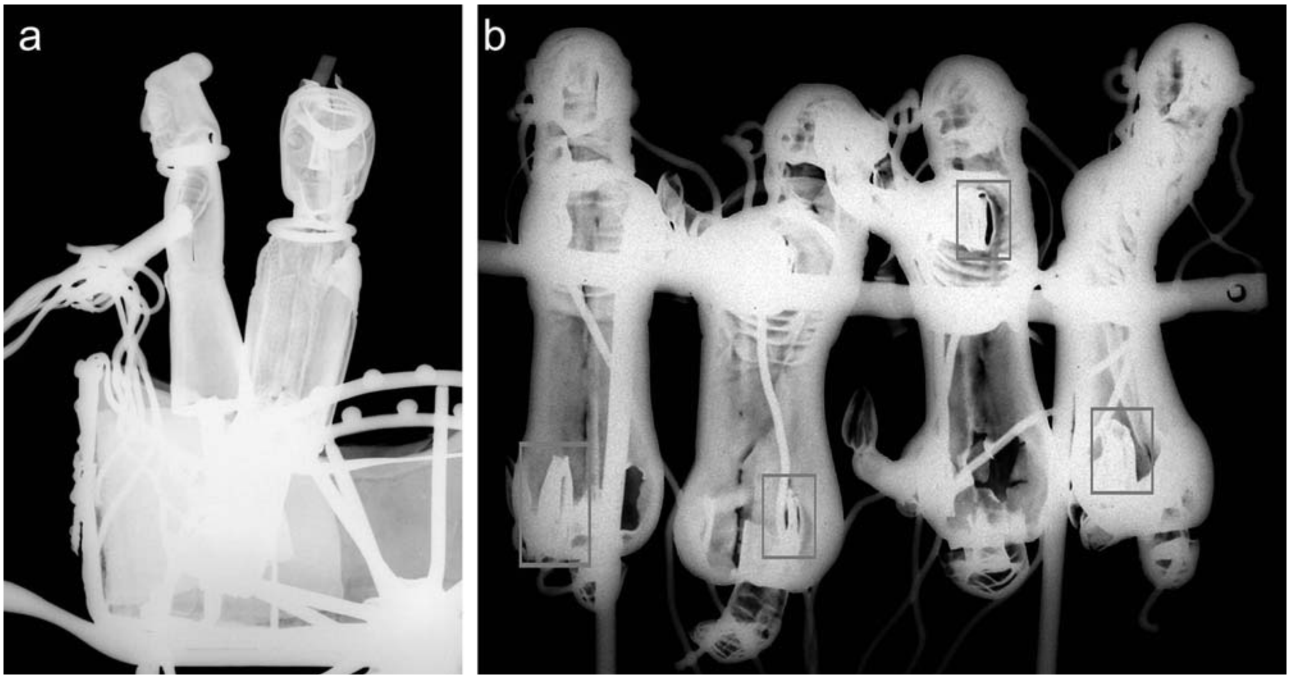

FIGURE 6. Details of the X-radiographs from Figure 5 showing the relatively dark, hollow cores of: (a) the figures in the chariot; and (b) the horses. The areas marked with rectangles show that the top parts of the hollow legs were inserted within the bodies of the horses

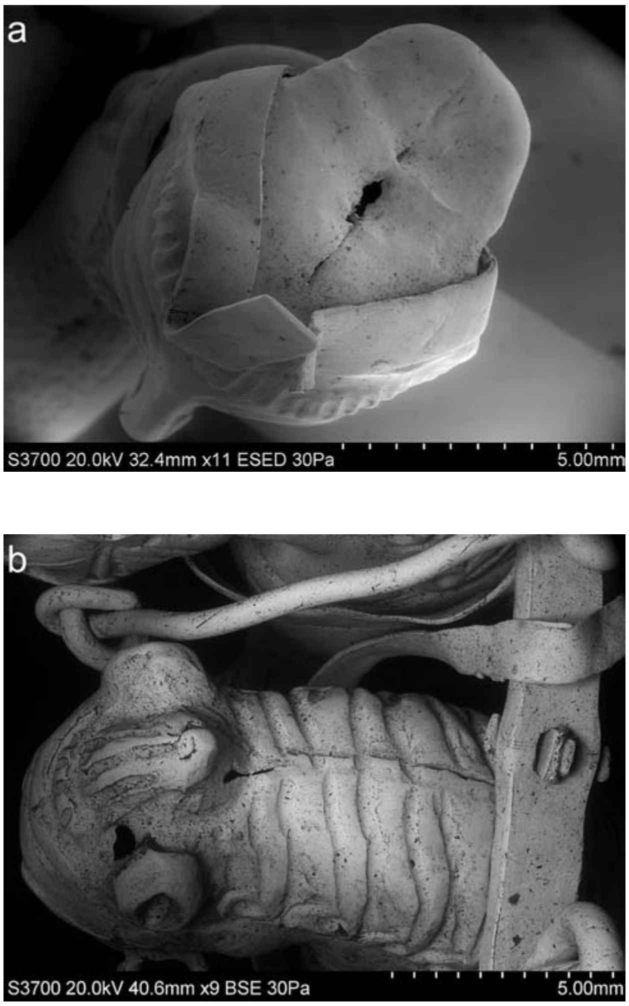

FIGURE 7. Details illustrating soldered seams joining two shaped gold sheets: (a) secondary electron image of the bun on the passenger's head; and (b) backscattered electron image of the centre of a horse's mane

FIGURE 8. Detail illustrating the overlap of the gold sheets forming the legs of the horses

of the passenger has been punched and chased to illustrate original contemporary fabrics and embellishments, Figure 2.

The horses are also hollow and are assembled in a similar way to the figures, but from more than two pieces. Their legs – of which only nine survive – are each made of two halves of gold sheet and the joint between the two halves can clearly be seen at the front and back of the legs where the two thin sheets of gold overlap, one being folded over the other and most likely soldered together, Figure 8. In the X-radiograph in Figure 6b it can be seen that the legs are themselves inserted into, and probably soldered to, the main body of the horse. The hollow tails are made of embossed gold sheets with a tip consisting of a twisted wire partially inserted into the hollow part, Figure 5a. X-radiography has shown that the tails were also mechanically inserted into a hole at the back of the horse (Figure 9a), with some solder applied locally around this hole to reinforce the whole structure, Figure 9b.

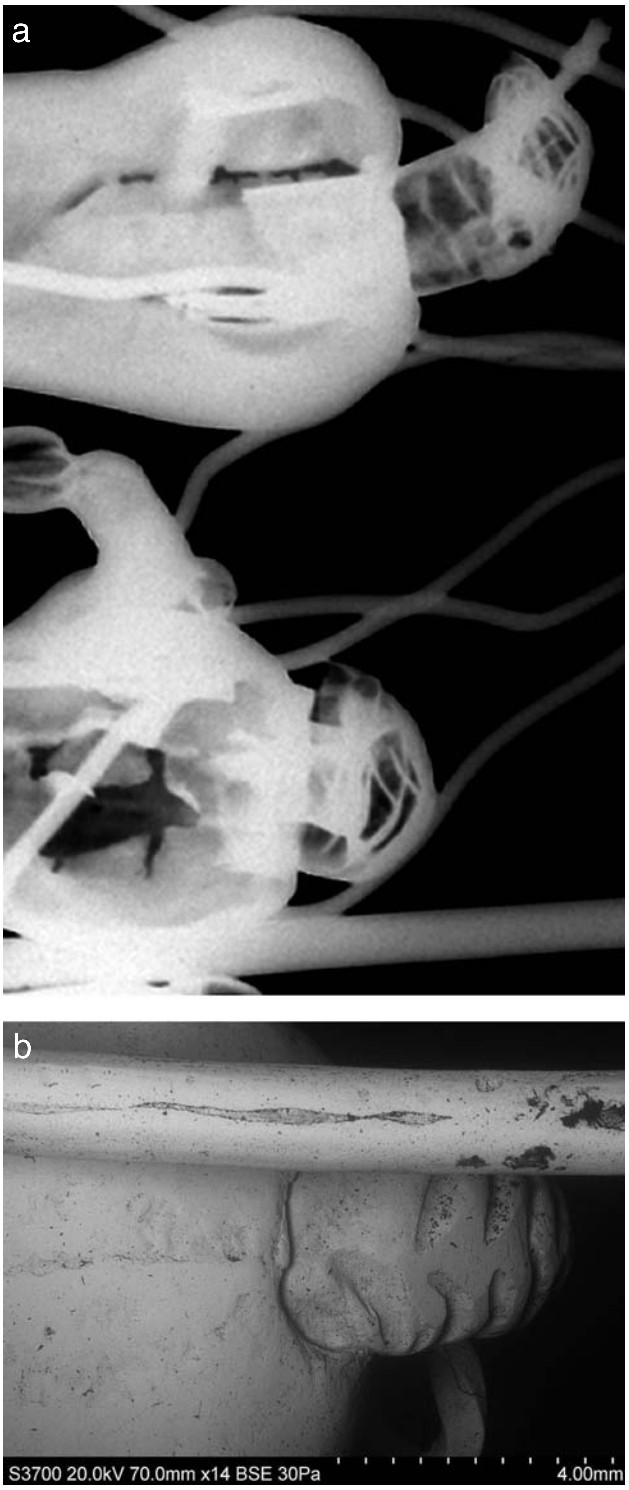

FIGURE 9. Details illustrating the attachment of the tails to the horses' bodies: (a) detail of the X-radiograph showing how the tails have been mechanically inserted into the bodies; and (b) backscattered electron image of the back of the right horse showing the local application of solder to reinforce the join

Manufacture of the chariot, reins and wheels

The chariot is made of a single sheet of gold that has been cut and folded to create the required shape. Evidence for this comes from the absence of seams and overlaps around the folds. It is possible that the front and the back of the folded sheet, which overlap on both sides towards the front, were soldered to render it stronger; the overlap on the front left corner is visible in Figure 2b. The sheet of gold has been fashioned by hammering, starting with an ingot produced by the crucible melting of alluvial gold particles to which copper had been added. This hammering and beating is seen in the characteristic contrast in density in the X-radiograph of the chariot floor, which arises from heterogeneity in the thickness of the sheet. One rivet mechanically secures the bench to the front of the chariot through a double strip that is probably soldered to the back of the rivet. This double strip passes through holes in the folded part of the bench and the front sheet of the chariot, and is itself folded at the back, Figures 2b and 10a. Three rivets at the back of the chariot also secure the bench in a similar way, Figure 10b.

The head of Bes on the front of the chariot would have been worked by repoussé and chasing of a gold sheet and then attached to the main body of the chariot. This head is also fixed to the front of the chariot through a pair of folded back strips.

Each individual rein is a twisted wire with a round section, while the two shafts attaching the chariot to the yoke are thicker round wires hammered from blocks of solid gold. The distinction between the two techniques employed to produce these wires can be observed by studying their seams: these remain straight on wires that have been hammered

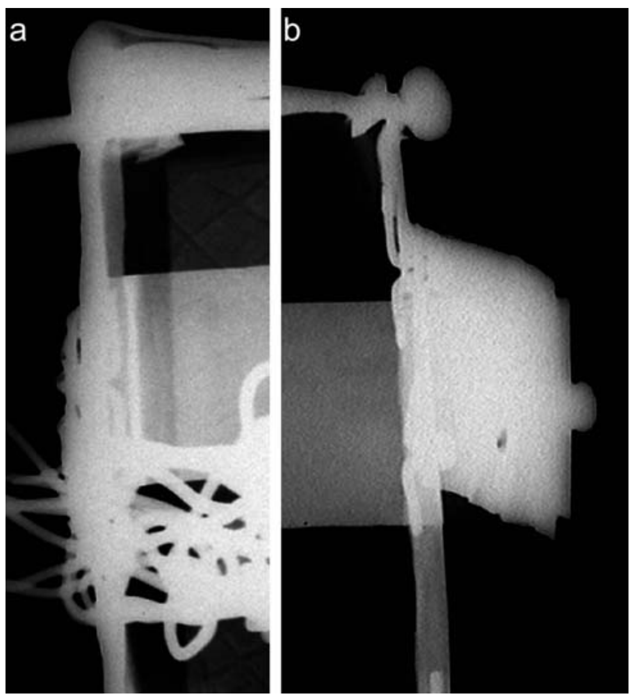

FIGURE 10. Details of the X-radiograph taken from the top showing the folding and riveting of the bench sheet at: (a) the front; and (b) the rear of the chariot

whereas they spiral along the length of those wires that have been deliberately twisted during the manufacturing process, Figures 9b and 11. The wires representing the reins are relatively thick at *c.*1 mm in diameter and they show more than one helical seam along their length, which would indicate the preferential use of block twisting [27–29]. The yoke is a square bar of hammered solid gold onto which the four terrets (each made of hammered wire curled in a loop) are soldered, Figure 12. The two remaining fan-shaped ornaments are made of hammered and cut sheet gold ending in a pair of strips that pass through the yoke and the shafts to secure them together. Of the original eight reins that run from the horses' bridles to the driver's hands seven remain. The reins are continuous with the driver's fingers and have been soldered to the hands: one thumb is clearly a rein while another displays the imprint of a chased fingernail, Figure 11a.

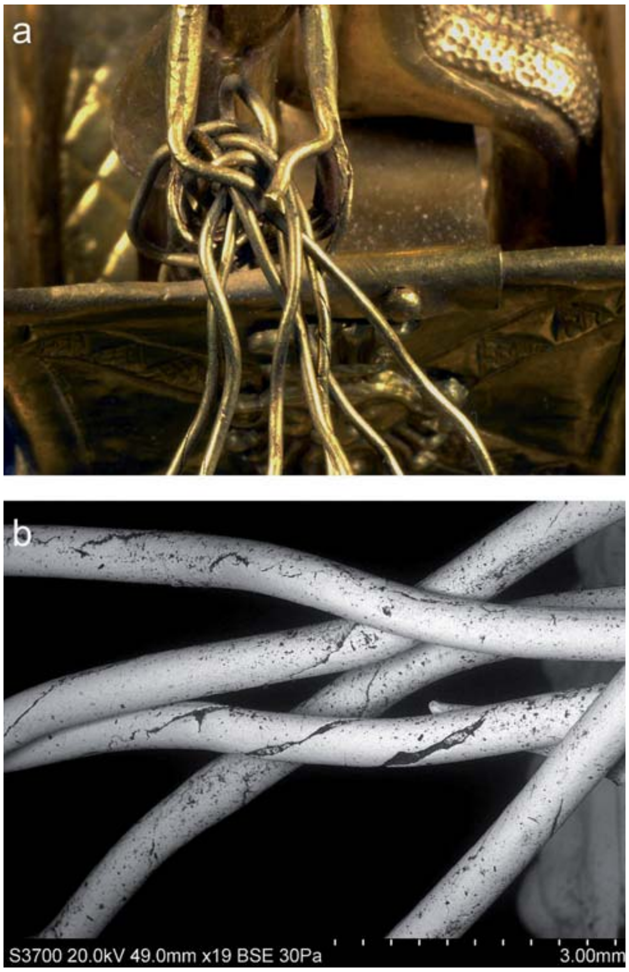

FIGURE 11. The twisted wires of the reins: (a) detail showing how one of wires is continuous with a finger and the engraved fingernail; and (b) backscattered electron image of the reins made of twisted wires. Note the difference in the course of the seams compared to that in the hammered wire seen in Figure 9b

Investigation of the construction technique of the wheels showed that each outer rim is a wire that has been hammered into a square section and the ends soldered together. This outer rim is covered by gold granules that have a diameter of *c.*1.5–2 mm. These granules are relatively regularly distributed around the circumference of the wheel and represent the studs that would have held the metal tyre to the wooden wheel on the life-size chariot; on the right wheel there are 29 granules, while the left has 27 granules and spaces between them that indicate that two are missing. These gold granules have been very carefully applied by soldering and the regularity in the spacing of the individually applied granules shows a sophisticated goldsmithing technique, Figure 13 [30, 31]. The granules were prepared beforehand to be of similar diameter, most likely by preparing a hammered solid wire of constant diameter and then cutting from it short fragments of equal lengths. These small pieces of wire would have been placed on a charcoal block and heated individually to melting point with a flame blown down onto the gold. The wheel rim would then have been marked with the regular spacing in preparation for the sequential soldering of individual granules. The granules could have been soldered either onto the flat wire before it was formed into the circular rim or onto the already curved wire, although the curved geometry of the latter would not allow all 29 granules to be placed and soldered in a single operation. By using a pencil-thin blown

FIGURE 12. Backscattered electron image of the head of a horse with part of the yoke and a soldered terret through which two twisted wires – the reins – pass

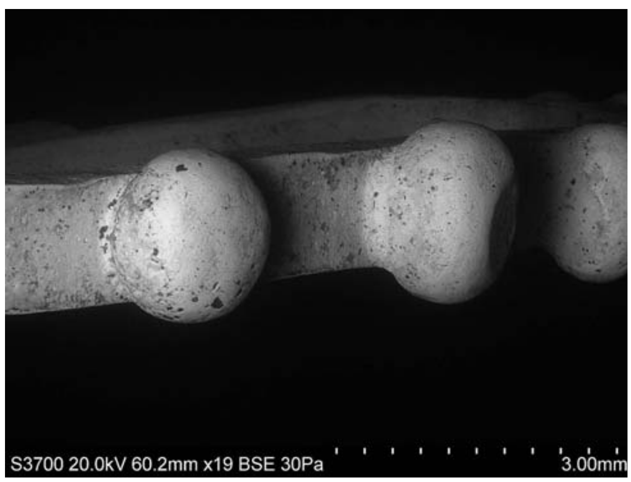

FIGURE 13. Backscattered image of one of the wheels showing the regular granules soldered to the rim

flame, heat could be concentrated on each granule and the associated application of solder on the rim to fuse them in place. A fine flame would be required to prevent overheating the adjacent granules, displacing them or causing them to fall off during the complex assembly operation.

The wheels are mechanically attached to each other by an axle that was made by hammering a rod of solid gold to give a round section. This axle crosses under the floor of the chariot, to which it is probably soldered, and the wheel hubs are inserted on its ends. The hubs are held in place by a spiral of wire that acts as a bearing, Figure 14. The connection mechanism is hidden beneath a flower-shaped gold sheet that acts as a cover for the hub. The rims of both wheels are maintained in a circular shape by spokes that have a round section. Each spoke has presumably been soldered to the central hub, with these joins hidden beneath the hub cover, but not all of them have been soldered to the outer rim. Several appear to have broken away from the rim leaving a characteristic solder mark on its inner surface. One spoke appears to be missing from the left wheel: the shape of the left hub cover, which hides the joins between the spokes and the hub, is a slightly less perfect flower shape than that on the right. This could, however, simply be due to damage during use and/or burial, rather than an intentional repair to hide the loss of one spoke.

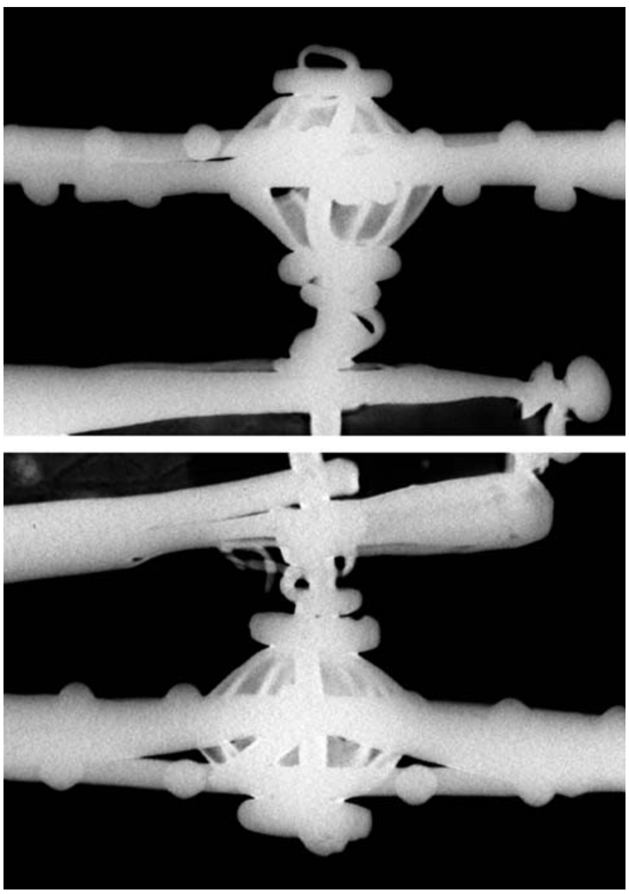

FIGURE 14. Details from the X-radiographs of the chariot wheels revealing their construction and turning mechanical features: the axle end reaches the internal flower-shaped sheet, a wire is coiled around the axle and goes through the hub to come out of the external flower-shaped sheet on the other side and is folded back inside

FIGURE 15. Backscattered electron image of the back of one of the horses where it has been mended, probably in antiquity, with an added piece of gold soldered onto the original body

MODIFICATIONS AND REPAIRS

The model has been repaired and restored on more than one occasion; the earliest phase of repairs appears to be ancient and was not recognized prior to the current analysis.

Ancient repairs

The backscattered electron image shows that the back of one of the horses was mended in antiquity with an additional fragment of gold sheet soldered onto the original body, Figure 15. This repair may have been carried out to conceal damage that occurred either during the manufacture of the artefact or while it was in use.

The tip of one horse's tail displays some green surface corrosion, indicating that this part of the tail is richer in copper and most likely made from a copper-based alloy; the same corrosion is observed on the upright pole supporting the bench on which the passenger sits. These two components are probably repairs made with debased metals or gold-plated copper, which have subsequently corroded during burial. Because of their locations, these components were not accessible for non-invasive analysis by XRF or EDX, so it was not possible to confirm the composition of the metal(s) used. An earlier colour photograph of the chariot group also shows traces of what appears to be copper corrosion on the faces of both figures, the belt area of the driver and the muzzle of the left horse [32; p. 27].

Conservation history at the British Museum

Prior to the creation of the Department of Conservation at the British Museum in 1975, the cleaning, restoration and mounting of objects was carried out by assistants based in the curatorial departments, occasionally guided by scientists in the Research Laboratory. Some of the former group, notably members of the Ready family, worked on objects across the collection and were highly skilled craftsmen. Unfortunately few records were made of these treatments, yet early photographs offer a means of mapping changes of appearance over time. In the case of the chariot, neither the photographs taken at the time of display in 1900/1901 nor for the first edition of the catalogue (published in 1905) show any obvious signs of restoration (Figures 1 and 2), while the earliest published photographs to reveal any significant signs of change date from the 1960s. The first major restoration of this object must, therefore, have occurred between these dates. There are two moments when changes in the displays might have triggered this, the first in 1932 and the second in 1958, and it was presumably on one of these occasions that the reins were straightened, the figures fixed to the cab, the distorted right wheel on the original photograph was repaired and the two wheels apparently swapped over. One of the two remaining fan-shaped ornaments was relocated to a different position on the yoke, whereas a third had by then become separated. Further small repairs were carried out in February 1975, in preparation for the opening of the gallery display later that year. The conservation record reports that the surfaces were cleaned with water containing a little neutral detergent and several areas were consolidated with HMG cellulose nitrate, including the point at which the figures are attached to the bench and the floor of the chariot, the underside of the axle and its junction with the wheels. Since 1975, the only further treatment comprised light surface cleaning with methylated spirit prior to display in 2005. No further conservation treatment has been undertaken on the occasion of this current technical examination, as the Museum's current policy is to reduce interventions to the minimum necessary to preserve the safety of the object, to use reversible treatments where possible and to avoid procedures or materials that may jeopardize the chance of using new scientific examination or analysis techniques in the future.

CONCLUSIONS

This scientific investigation has provided important new insights into how one of the most distinctive items in the Oxus Treasure was made. This gold chariot model is a result of a variety of goldsmithing techniques, including hammered and folded sheet gold, hammered and twisted wires and granulation and of the application of complex mechanical fixing and soldering methods. A wide range of decorative techniques, such as chasing, repoussé and punching, was used to add finishing details to the chariot, figures and horses. This artefact is a fine illustration of the continuous development of the production of complex three-dimensional objects. This goldworking technology appears to have been relatively challenging, particularly because complete soldering of components was clearly difficult to achieve. The solution adopted by the original goldsmith in this case seems to have made use of localized soldering in conjunction with mechanical fixing. The combination of these intricate techniques allowed the goldsmith to produce a model that was a close representation of a real, contemporary chariot.

The metal chosen for this chariot was natural alluvial gold containing a small amount of silver, to which copper was added. The presence of platinum group element inclusions is consistent with earlier research findings on other pieces in the Oxus Treasure [6], and supports this alluvial origin of a natural gold–silver alloy. This study also reveals ancient repairs and early attempts at restoration within the Museum for which no records otherwise appear to survive. These modifications include the replacement and/or addition of solid gold wires by copper wires, which may be gold plated, and later use of transparent resin to hold the driver, the passenger and one wheel in place.

This research illustrates that even for well-known objects significant new information can be revealed by careful detailed scrutiny and the application of scientific techniques for examination and analysis. Further research is planned to address the questions raised by this study, including a more detailed examination of the joining techniques that will include a comparison of this distinctive object with similar artefacts from the Oxus Treasure, such as other horses, another chariot and several statuettes. These scientific and technical studies of the Oxus Treasure continue to shed light on the sophisticated manufacturing technology of the Achaemenid Empire.

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NOTE

1. Pre-Islamic Iranian objects were displayed, for example, on the Persian Landing at the head of the North West Stairs (1958), in the Iranian and Anatolian Rooms (1975–1990), in the Ancient Iran Gallery (Room 49, 1994; Room 52, 1995–2005) and most recently in the Rahim Irvani Gallery (opened 2007). Within the British Museum objects from the Oxus Treasure have featured in exhibitions including *Royal Persia* (1971), *Forgotten Empire* (2005) and *The Changing Museum* (2006). Loan exhibitions have included those to the State Hermitage Museum (1979) and La Caixa (2006).