Research Article

A Closer Look at a Polychromed Bronze Statue of Osiris from the Basement of the Egyptian Museum, Cairo

Eid Mertah,[1] Wafaa Mohamed,[2] Elisabetta Zendri,[3] and Andrea Argente Barberán[4]

[1]Egyptian Museum in Cairo, Ministry of Tourism and Antiquities, Cairo 11566, Egypt
[2]Conservation Department, Faculty of Archaeology, Cairo University, Cairo 11566, Egypt
[3]Department of Environmental Sciences, Informatics, Statistics, Ca' Foscari University, Venice 30031, Italy
[4]Universitat Politècnica de València, Facultat de Belles Arts BBAA, Valencia 46022, Spain

Abstract

A polychromed hollow-cast bronze statue, missing its head and feet, is the object of our study and intervention. It is part of the large collection of bronze statues depicting the god Osiris in the Egyptian Museum in Cairo. Until recently, it was stored in the basement, where it had been placed since it was recovered from excavations, the trace of which has been lost. Until now, no work had been done on it. This article describes the interventions that we carried out on it. The surface of the statue was investigated to get information about the metal, the decorative materials, the corrosion, and the deposit accumulations on its surface. Various analyses were carried out to help identify the type of patina and alterations caused by burial. Digital light microscope, X-ray radiography, X-ray fluorescence, and X-ray diffraction were used to identify the components, providing a better understanding of the object's deterioration and its interaction with its environment. The results of the non-invasive, non-destructive investigation methods, as well as the data from previous studies were used to create a conservation action plan. Alongside the analyses and studies, mechanical cleaning was carried out, removing the dirt and corrosion with the help of different tools such as micro-motors, scalpels, and ultrasonic pen. Hidden characteristics and remains of polychromy were uncovered. We also detected the remains of gold, Egyptian blue and lapis lazuli, materials used to decorate the statue. A final cleaning of the surface was carried out by using an "Nd:YAG" laser.

Keywords: Osiris, statue, bronze casting, gilding, Egyptian blue, laser, corrosion
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يتناول موضوع الدراسة تمثال برونزي مجوف متعدد الألوان، فاقد الرأس والقدمين. وهو جزء من مجموعة كبيرة من التماثيل البرونزية التي تصور الإله أوزوريس في المتحف المصري بالقاهرة. وحتى وقت قريب، كان مخزنًا في بدروم المتحف المصري، حيث تم وضعه منذ أن تم إكتشافه من الحفائر، وقد فقد كل المعلومات الخاصة به. وحتى الآن، لم يتم إجراء أي عمل عليه. تصف هذه المقالة التدخلات التي أجريناها عليه، فتم فحص سطح التمثال للحصول على معلومات حول سبيكة المعدن، والمواد التي أستخدمت فى زخرفته، والتآكل وتراكم التكلسات على سطحه. وأجريت تحليلات مختلفة للمساعدة في تحديد نوع الباتينا والتغييرات الناجمة عن عملية الدفن. تم استخدام الميكروسكوب الضوئي الرقمي، والتصوير بالأشعة السينية، والتحليل بتفلور الأشعة السينية المحمول، وكذلك بحيود الأشعة السينية لتحديد المكونات، مما يوفر فهمًا أفضل لحالة تدهور القطعة وتفاعلها مع بيئتها. كما تم استخدام نتائج الفحص والتحليل المختلفة الغير متلفة، وكذلك المعلومات من الدراسات السابقة لوضع خطة عمل لترميم القطعة الاثرية. إلى جانب التحليلات والدراسات السابقة، تم إجراء التنظيف الميكانيكي، وإزالة التكلسات والتآكل من أعلي سطح التمثال، وذلك بمساعدة أدوات مختلفة مثل ماكينة الفريزة والمشارط وقلم الموجات فوق الصوتيه. تم الكشف عن العناصر المخفية وبقايا الألوان. كما اكتشفنا بقايا تذهيب وتطعيمات من الأزرق المصري حجر اللازورد، وهي المواد المستخدمة لتزيين التمثال. تم إجراء التنظيف النهائي للسطح باستخدام جهاز ليزر "Nd:YAG".

الكلمات المفتاحية: أوزوريس، تمثال، صب البرونز، التذهيب، الأزرق المصري، الليزر، التآكل

1. Introduction

The statue which is the object of this study depicts Osiris, god of agriculture, fertility, and resurrection. Bronze statues in his likeness constitute a significant part of all Egyptian collections. Thousands of bronze sculptures of Osiris can indeed be found in museums worldwide, and thousands of them were excavated in certain cultic places, notably at the Serapeum in Saqqara, at Sais, at Medinet Habu, or in the Cachette of Karnak (Mariette 1882; Daressy 1897; Daressy 1906; Hölscher 1939; Hölscher 1954; Leclère 2003; Coulon (ed.) 2010)). Given their number, it could even be said that the Osiris bronzes are one of the main artistic testimonies from the First Millennium BC (Griffiths 1982, col. 623–633).

In exhibition and museum catalogs, as well as on labels in galleries, bronze statues often bear the label "Late Period", without more specification, and often even erroneously. Indeed, despite their numbers, this category of statues remains largely unstudied. The pioneering studies of the repertoire of Osiris statues were carried out by G. Roeder in Hildesheim (1937) and Berlin (1956). While these publications remain essential, they can be supplemented and, where necessary, corrected, in the light of new archaeological discoveries, and thanks to advances in our knowledge of archaeological contexts, bronze technology, and the evolution of style during the First Millennium BC.

The statue that is the subject of this study and article has undergone oxidation and deterioration over time. Moreover, it lacks its head and feet and was covered by a thick layer of corrosion. In different spots, we could still find active corrosion, as well as other aspects of deterioration such as thick crusts of archaeological soil, cracks, and microcracks (Figures 1, 2, and 3). This endangered the integrity of the work, and for this reason, it was necessary to intervene. A technical and documentary study of the work was conducted, followed by a proposal for work to be carried out on the object.

FIGURE 1: Front of the statue prior to intervention.

FIGURE 2: Back of the statue prior to intervention.

The restoration process was done at the restoration laboratory of the Egyptian Museum in Cairo and took a few months.

Thanks to the nondestructive methods of analyses, followed by mechanical cleaning, important aspects concerning the manufacturing technique of the object were discovered.

FIGURE 3: Right and left sides of the statue prior to intervention.

2. Objectives

The main goal of our work as conservators-restorers is not only to preserve the artifacts for future generations and make them visible to the public but also to produce research. A conservative intervention was therefore the opportunity to deeply study the statue.

Before proceeding with the cleaning, restoration, and conservation of the statue, it had to be placed in its historical and functional context, in order to understand its meaning and to virtually reconstruct its original appearance, by comparison with similar objects. This recontextualization within a stylistic and iconographic panorama also allows us to date the object, despite its fragmentary state.

The identification of the materials constituting the object of study was made using noninvasive analysis techniques. No samples were taken from the statue itself, though some were taken from the layers of soil and corrosion covering it, as well as from the core of clay used during the hollow-casting procedure. Through these procedures, we were able to identify the alloy and inlaid materials and reconstruct the production techniques, as well as their decay processes.

This study is part of a wider project, led by one of the authors, Eid Mertah, in the framework of his doctoral thesis: an overview of large bronze statues bearing the effigy of the god Osiris, produced throughout the First Millennium BC.

3. Contextualization and Iconography of the Object

Even though any indication concerning the provenance of the object has been lost, it is likely that it comes from one of the four main sites that yielded large bronze of the god Osiris at the end of the 19th and in the early 20th century: the Serapeum at Saqqara, the temple of Medinet Habu, Sais, and the Cachette of Karnak. In all cases, bronze statues, together with other artworks and artifacts, including stone and wooden statuary, as well as cultic objects, were buried in sacred deposits or under the temple pavement, at the end of the First Millennium BC. The statues found in these four important contexts were brought to Cairo (first in Boulaq, then in the Egyptian Museum). Most of them were restored and put on display, but a group of large bronze sculptures were left untreated in the basement of the museum.

Bronze objects, in particular statues of sacred animals, kings, and deities, became very popular from the Late New Kingdom Period and forward, even though we can find bronze statues previously. The increase in the production of these statues comes from what scholars believe were different temple workshops around Egypt (Gombert 2019: 203-204). The most substantial number of productions was made between the Third Intermediate and the Ptolemaic Periods (i.e., over the whole First Millennium BC). Artists created bronze sculptures both for cult purposes and as votive objects—these two functions were not mutually exclusive, as an object deposited as an ex-voto could later become part of a set destined to serve as the main focus of worship in a temple. This is the case of the hundreds of bronze Osiris statues found in their original context, still in the rooms of a collapsed temple, at the temple of Ayn Manawîr (Wuttmann et al. 1996; Gombert 2019: 197-198), dating from the 5th century BC. Different reasons may have led to the spectacular increase in the production of bronzes depicting the god Osiris over the Third Intermediate and Late Periods, including the development of bronze production in general, perhaps a larger affordability, at least to a certain extent, as well as the development of religious practices and a growing access to the acquisition of bronze ex-votos by a larger range of faithful.

Osiris bronzes appear in deposits in temples that were not dedicated to Osiris himself; therefore, they must have had specific meaning and function. Since Osiris is a very ancient god, its iconography evolved over time. Large-scale studies such as that in the course by Florence Gombert, based on the statues found in Ayn Manawîr and Saqqara's Serapeum, allow us to draw tendencies and associate specific forms to certain places and moments in history (Gombert 2019: 203–205).

The statue which is the focus of this study can be dated to the Third Intermediate Period, according to both its stylistic features and its manufacturing technique. The closest examples are London BM EA 60718, BM EA 60719 (McArthur et al. 2015), New York MMA 41.6.4 (Hill and Schorsch 2016: 274–287, figs. 15-16), and Cairo Museum JE 100381 (Mertah and Mohamed 2023). Most were made according to the hollow-casting technique. All show the god standing with arms crossed on the chest. They all have rounded faces with particularly large eyes, which were inlaid, full cheeks, a relatively small mouth with full lips, and a large rounded nose, all stylistic features of the 21st-22nd dynasties that follow the model of the works of art of the 19th dynasty. In our case, although the statue has lost its head, the elongated body proportions, the position of the arms, and the manufacturing technique are sufficiently close to them to convince us that they belong to the same (or to a similar) production. Furthermore, the piece was found in the basement of the Egyptian Museum together with JE 100381 (Mertah and Mohamed 2023), and it is likely that they came from the same context and were brought at the same time, presumably at the beginning of the 20th century.

4. Technical Study of the Osiris Statue

4.1. Materials and Methods

The preserved part of the statue is 55.5 cm high, 18.8 wide, and 9.5 deep. The thickness of the metal at the level of the ankles is between 0.22 and 0.34 cm and at the level of the neck between 0.2 and 0.4.

A digital reconstruction based on prior studies and other statues in a better conservation state was done to understand better the morphology of the object and determine the original height of the statue (Mertah and Mohamed 2023: 919–926). Including the missing parts (base, feet, head, and crown), the statue must have been ca. one meter high (Figure 4).

FIGURE 4: Digital reconstruction of the statue.

After mechanical cleaning, we were able to see under the earthen concretions that the crossed hands were holding the canonical scepters.

This study brings together the data obtained by various investigative methods, which make it possible to know and identify the materials and techniques that make up the statue.

Digital Light Microscope
The surface and the remains of the inlays were examined with a VHX-2000E Keyence digital light microscope. Examination by using this kind of microscope helps to have a better look at the state of conservation of the surface and see more details that cannot be seen with the naked eye, like remains of pigments, gold, or microcracks.

X-Ray Diffraction (XRD)
This method of analysis was conducted using the Bruker D8 Discover with DAVINCI design. Through this device, ease of use with real-time component detection was permitted by a plug-and-play functionality.

Eight samples of the layer of soil and corrosion covering the surface of the statue were collected from different parts of the statue's surface. These samples of soil, corrosion, white layer, and detached pigment were taken carefully from the deteriorated surface of the statue, from both the front and the back side of the statue, for XRD analysis. This may provide information not only about the statue's components but also about the archaeological environment in which it was buried, as well as about the products causing the corrosion (Abdelbar 2021: 1409-1410; Elashery 2023: 26; Rifai 2023:25).

Portable X-Ray Fluorescence (pXRF)
X-ray fluorescence analysis was conducted using a portable Elio Spectrometer (Elio Device SN 177), XGlab srl, Milan. The instrument can detect elements from Na to U, with a field of analysis extending between 1 and 50 keV. X-ray radiation is generated using an Rh tube, with an electron accelerating voltage from 10 to 50 kV and a filament current from 5 μA to 200 μA.

The materials detection procedure was carried out in the open air.

Analysis by pXRF is a nondestructive technique that can tell us a lot about the elemental chemical composition of the metal substrate and give us a general idea of the processes that led to the corrosion of the statue (Ferretti 2007: 1514-1515; Ghoniem: 2014: 40).

X-Ray Radiography
Finally, radiography was carried out using an X-Ray Generator Specifications: Radioflex RF-200SPS, with a tube voltage of between 80 KV and 200 KV, and a tube current fixed at 5 MA. The X-Ray tube is a ceramic tube, the weight of the generator is 15 kg, while the weight of the controller is 14.5 kg. We used a wireless digital detector (image size 16x16 inch, active area 405 mm × 405 mm; flat panel in amorphous silicon; scintillator material is gadolinium oxysulphide (GOS); weight 5 kg).

A radiographic study was fundamental to visualize the internal structure of the statue (Figure 5) and to learn more about the way it was manufactured (Rifai 2023:25). X-ray radiography can also help to find aspects of deterioration, such as cracks and microcracks, as well as missing parts on the surface below the corrosion of the body of the statue (Calza 2015: 326-327).

Multispectral Imaging
Multispectral imaging was performed using a Kolari Vision Canon EOS RP Full-Spectrum UV/IR Camera Forensics Kit. The camera is a Converted Canon EOS RP and includes a Canon 50 mm f/1.8 STM lens. This noninvasive technique that combines imaging and spectroscopy helps to detect pigments and to visualize the distribution on surfaces of different chemical compositions. The information provided by this type of test makes it possible to have a general knowledge of the corrosion patina and its state of conservation, as well as to establish a better intervention plan (Catelli 2018: 2-3). In the case study of that article, that technique was used to investigate the blue pigment at the scepter of the statue. This technique was applied before, during, and after the restoration process. Multispectral imaging in IRF mode helped to recognize traces of Egyptian blue on the scepters (Figure 16).

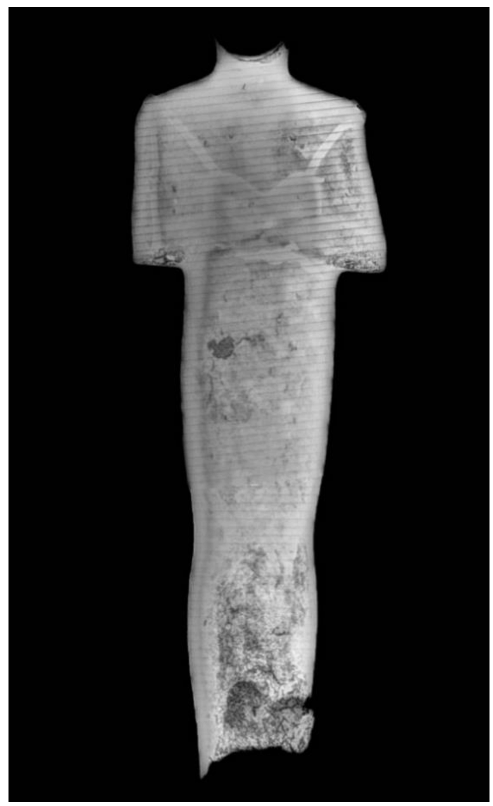

FIGURE 5: Examination by using portable X-ray radiography is a nondestructive technique that helps to learn about the internal structure of the object. KV 80, MA 5, and D. 1.5.

4.2. Composition

XRD Analyses
Eight samples were analyzed by XRD to study the materials covering the surface of

the statue, the soil, corrosion products, white layers, and pigments.

TABLE 1: XRD sample description.

Sample number	Description
E2	Front side, knee level (Soil + corrosion)
E4	Under the right arm (Soil + corrosion)
E5	Under the left arm (corrosion)
E7	From the right forearm (Soil + corrosion)
E8	Right side, under the arm (Corrosion)
E9	Above the bottom (Corrosion + white layer)
E12	Core from inside the neck
E13	Blue pigment at the heqa

The archaeological soil which was covering the statue consists of quartz, kaolinite, and albite. XRD analyses of the archaeological soil samples show evidence of corrosion processes through the presence of small quantities of corrosion products (atacamite and nantokite) (Figures 6, 7, and 8).

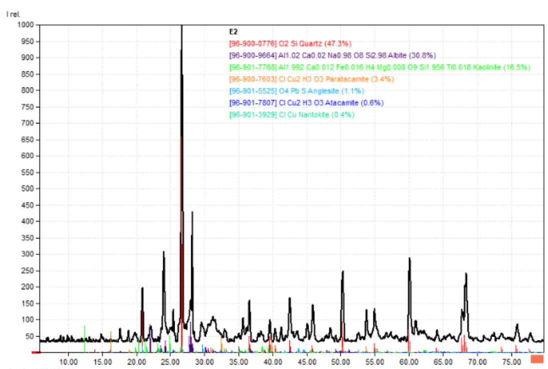

FIGURE 6: XRD spectrum for the archaeological soil sample E2, taken from the surface of the statue, front side, knee level.

The samples taken from the corrosion layers close to the surface (Figures 9, 10, and 11) show the presence of a mixture of paratacamite, atacamite, nantokite, and chalcocite. The presence of cuprite in the patina layer was also detected (Figures 9, and 10).

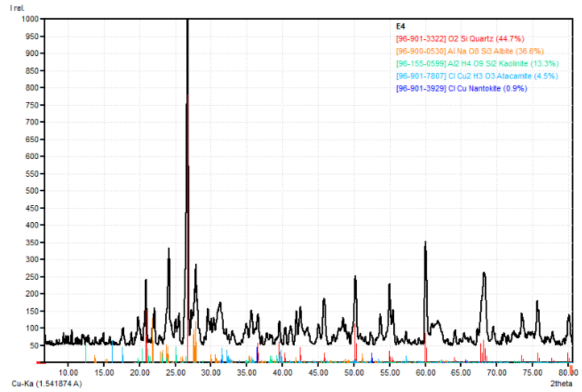

FIGURE 7: XRD spectrum or the archaeological soil sample E4, taken from the surface of the statue, front side, under the right arm.

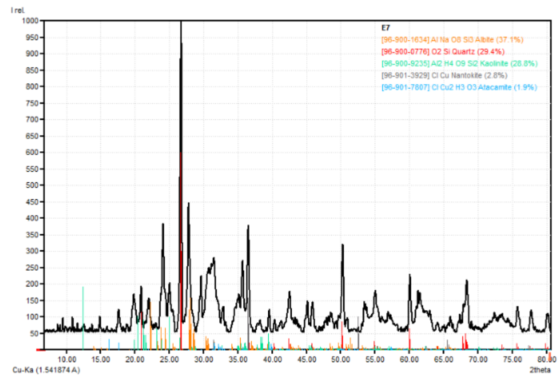

FIGURE 8: XRD spectrum for the archaeological soil sample E7, taken from the surface of the statue, on the right forearm.

The white layer still covering parts of the surface of the statue is calcium carbonate. This layer is now mixed with the corrosion products developing above the surface of the statue (Figures 9, 10, and 11).

The core of the statue is made of clay. The analysis of the sample revealed that it is composed of quartz, kaolinite, and albite, as well as a little bit of calcite (Figure 12).

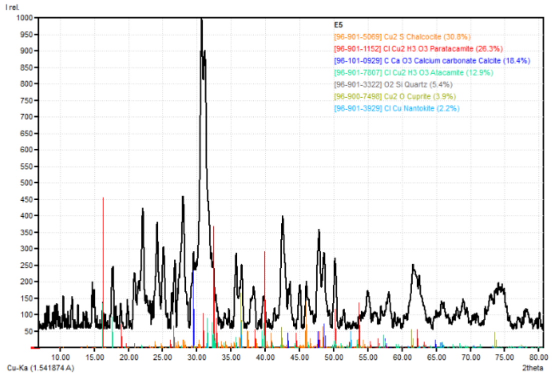

FIGURE 9: XRD spectrum for the corrosion and the calcium carbonate layer, sample E5, taken from the surface of the statue, under the left arm.

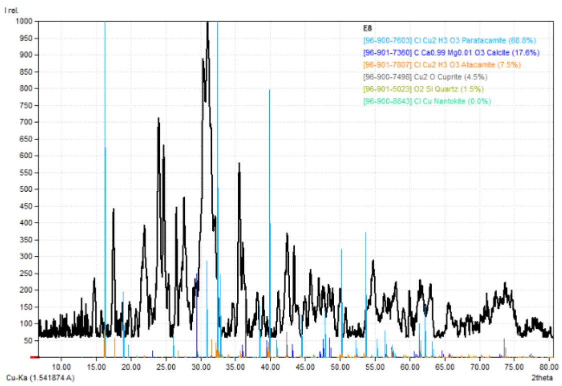

FIGURE 10: XRD spectrum for the corrosion and the calcium carbonate layer, sample E8, taken from the surface of the statue, right side, under the arm.

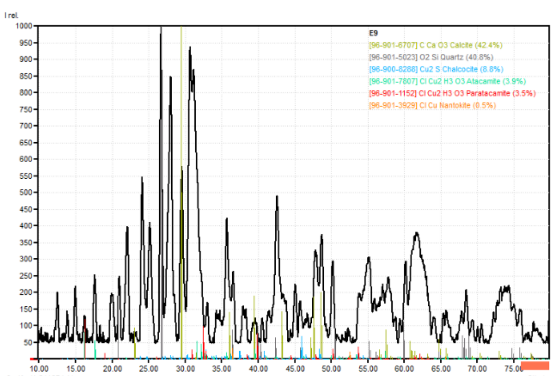

FIGURE 11: XRD spectrum for the corrosion and the calcium carbonate layer, sample E9, taken from the surface of the statue, backside, above the bottom, and behind the left arm.

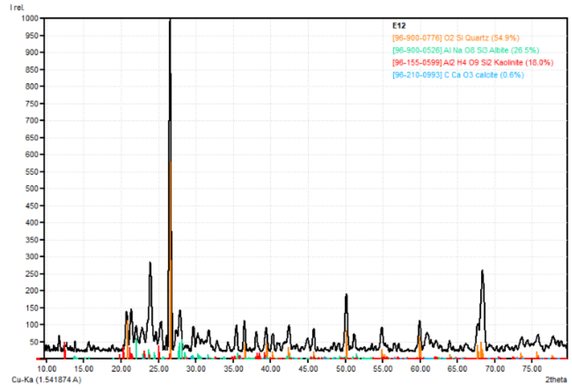

FIGURE 12: XRD spectrum for the core of the statue, sample E12, taken from inside the neck.

The blue pigment on the scepters is Egyptian blue, as reported by the XRD analysis (Figure 13) and multispectral imaging in the IRF mode (Figure 16) (MERTAH and MOHAMED: 2023: 922).

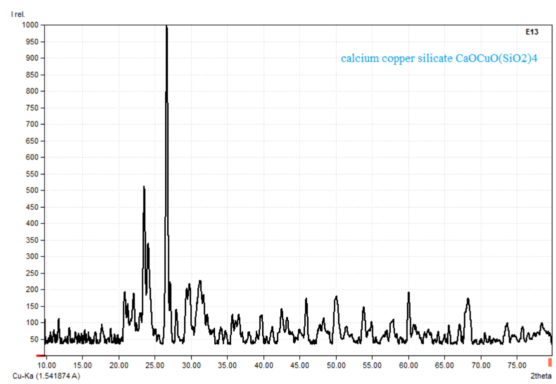

FIGURE 13: XRD spectrum for the blue pigment at the heqa, sample E13.

pXRF Analysis

A total of twenty-five points were measured on the front and the back of the statue (Figures 14 and 15), using a portable X-ray fluorescence device, to study the composition of the statue. These points were chosen to cover all the different materials making up the statue: metal, clay core, white layers, pigments, gold remains, and stone inlays.

Alloy

Ten measurement points were taken in relation to the alloy material. The statue is mainly composed of copper, lead, and tin, with a large concentration of copper and lead (Table 2). The lead content is even higher on points 8 and 9, as reported in Table 3. This metal does not affect the solidification process of the structures. However, due to its immiscible characteristics, and since it is one of the heaviest metals on earth, it can create an irregular distribution of particles (Wang et al. 2024: 881–896).

FIGURE 14: Front XRF points.

TABLE 2: XRF results on points 1:7 and 10 of the alloy.

Analyzed point no.	Element %			
	Cu	Pb	Sn	Fe
1	52,18	39,33	7,62	0,87
2	57,47	33,95	7,78	0,78
3	50,51	42,05	6,33	1,11
4	45,81	42,01	10,44	1,74
5	59,74	30,54	8,72	1,00
6	58,84	31,27	9,24	0,65
7	57,50	34,50	7,57	0,43
10	57,70	32,21	8,80	1,29
AVERAGE	54.97	35.73	8.31	0.98
STDEV	0.0492	0.0472	0.0126	0.0041

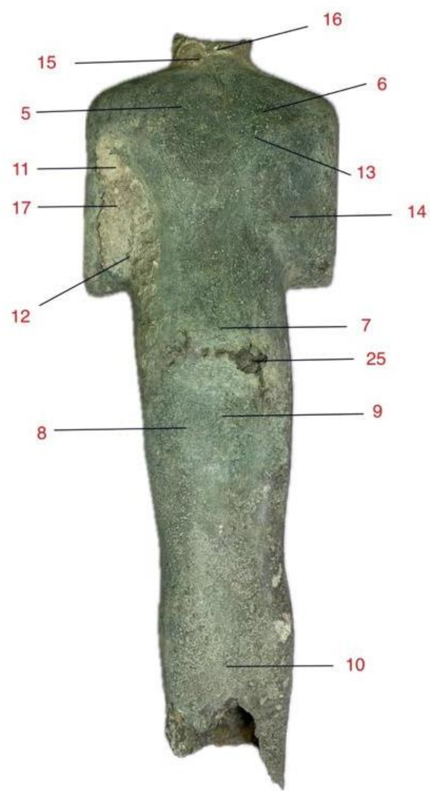

FIGURE 15: Back XRF points.

TABLE 3: XRF results of the analyzed points 8 and 9.

Analyzed point no.	Element %			
	Cu	Pb	Sn	Fe
8	17,33	78,53	3,49	0,65
9	13,86	80,86	4,40	0,88

The lost-wax casting process for bronze statues was carried out by casting from top or bottom according to the shape of the mold. Further, it is known that lead is a heavy element that normally concentrates more in the lower parts in the casting process (this phenomenon is frequently observed on other Osiris bronze statues, in the material studied as part of Eid Mertah's doctoral thesis).

However, in our case study, it is difficult to detect the position of the casting, whether the statue was cast upside down (as it is often documented) or in another way.

Inlays and Surface Decorations
For the surface decorations, the craftsmen used a variety of materials such as pigments, gold, and stone inlays, the use of which had an important significance in the symbolic world of ancient Egypt.

The main component of the white part on the surface of the statue, which we can call 'the preparation layer', is calcium, according to the pXRF results. The high percentage of calcium may indicate that the preparation layer used before the application of gold is calcium carbonate, which is very common in this type of statuary, and that confirms the interpretation of the XRD analysis (Mertah and Mohamed 2023: 922).

Finally, the test carried out on the decorations above the preparation layer determined that the statue was at least partially gilded, notably on the scepters and necklace and possibly other parts (Figure 17). Points 22 and 23 measured with the pXRF (Figure 14) indicated that the gold leaf which was used to decorate the statue contains some silver. We cannot exclude that the whole statue was gilded, as attested by other examples (Mertah and Mohamed 2023: 921-922).

FIGURE 16: Egyptian blue appears clearly on the scepters by multispectral imaging (IRF mode). From left to right: photos taken before, during, and after the cleaning process.

Egyptian blue and precious stones were also used to decorate the scepters (Figures 16 and 17). The pXRF measured points 18 and 20 show the main components of Egyptian blue (silica Si, calcium Ca, and copper Cu), information confirmed by the results of the XRD analysis and multispectral imaging in IRF.

During the cleaning process, the appearance of the Egyptian blue could be seen step by step (Figure 16). Cleaning was carried out under a microscope to avoid removing any residual Egyptian blue.

Point 19, measured on a blue fragment by pXRF, shows the presence of silica (Si), calcium (Ca), sulfur (S), and chlorine (Cl). These are the main components of lapis lazuli (together with the light elements sodium (Na) and Aluminium (Al), which cannot be detected with this type of pXRF). The morphology of the lapis lazuli could be seen under the microscope as well (Figure 17).

The Core

The core used during the hollow-casting process was still in position. Two points were measured by pXRF, one from the core of the neck and the other one from the hole at the back of the statue (measured points 24 and 25). The two main elements are silica (Si) and calcium (Ca), which confirms that the core is made of clay.

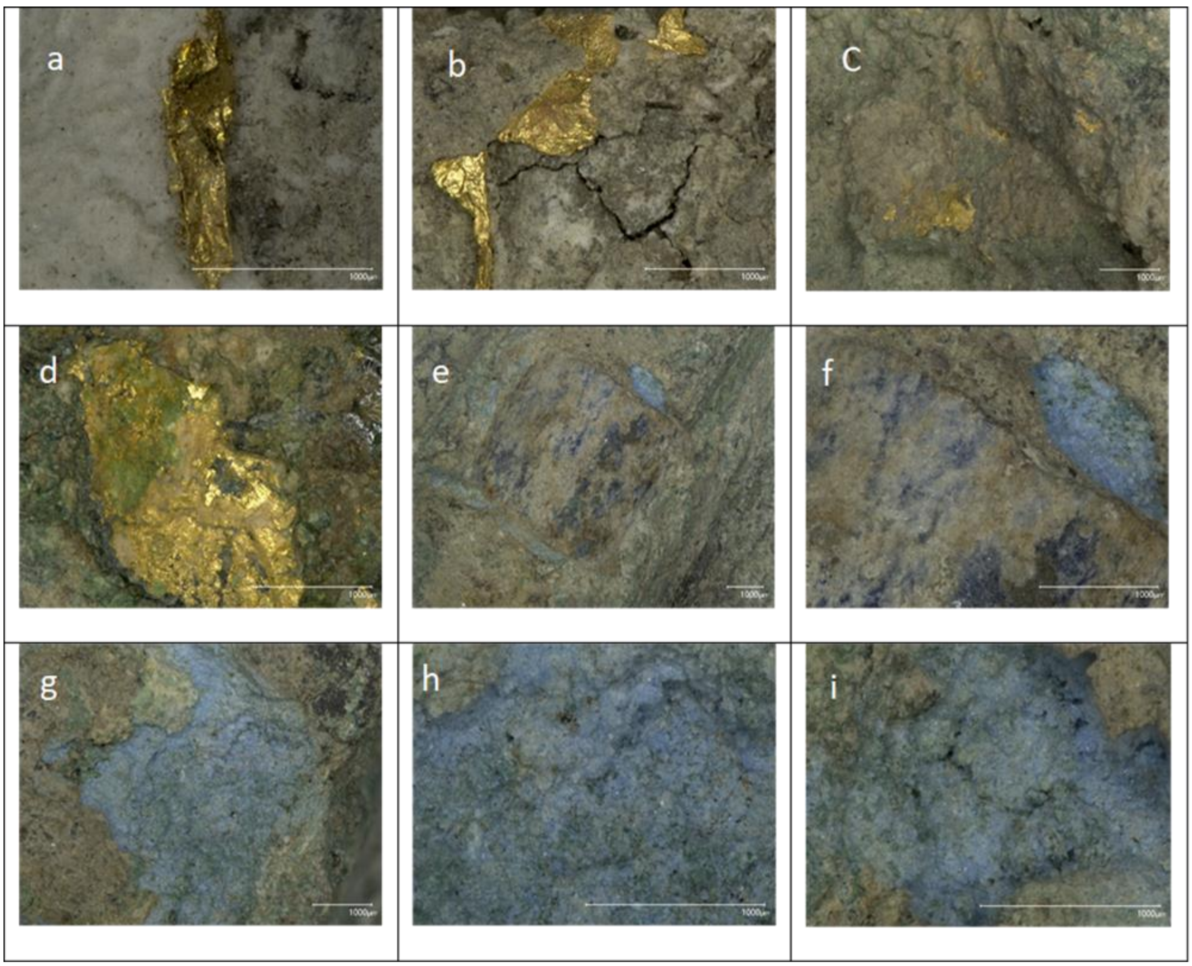

FIGURE 17: Digital light microscope imaging of some details of the gilded and the inlaid parts of the statue. Figures (a), (b), (c), and (d) are photomicrographs showing the remains of the gilded layer on the statue (a) on the left side of the neck, (b) on the proper right of the chest, (c) on the internal corner of the nekhekh, and (d) on the outer side of the nekhekh. Some green corrosion could be seen on it. (e) Photomicrograph showing the shape of the stone inlays at the *Heqa* "Lapis Lazuli". (f) Photomicrograph showing details of how the Lapis Lazuli stone was inserted inside a paste from Egyptian blue. The connection between the stone and the Egyptian blue could be seen as well. (g, h, and i) Photomicrographs showing the remains of the Egyptian blue on the statue (g and h) at the *heqa* and (i) at the *nekhekh*.

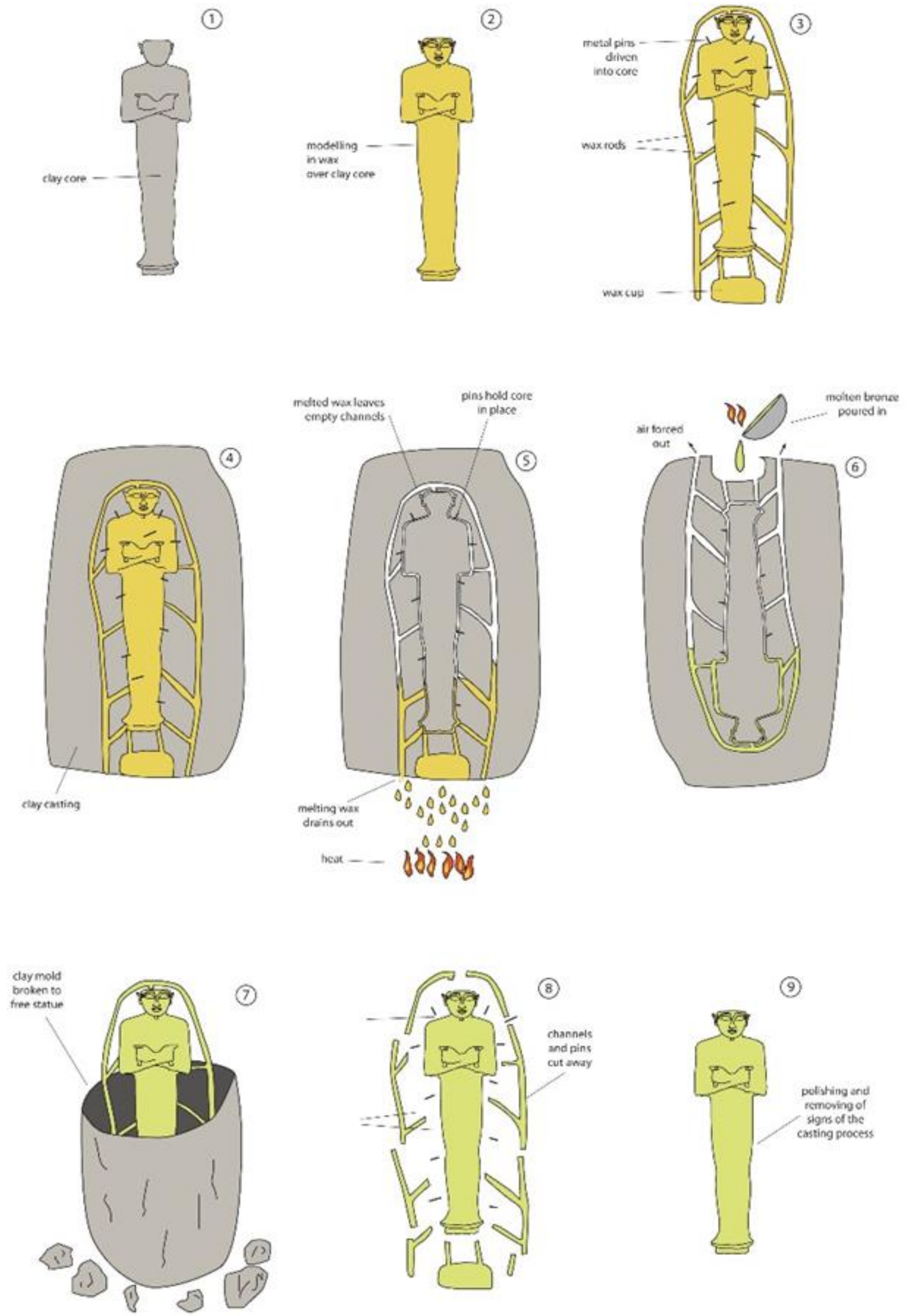

FIGURE 18. Illustration of the process of the lost wax © Simon Connor (Mertah 2021: 84).

4.3. Creation Process

The Technique of the Lost Wax

The technique of the lost wax is a sculpting method for creating bronze metal statues that are still used in our present time.

The first evidence of this kind of metalworking is from 5,000 years back by Egyptians and continued to be used in various cultures, until modern times. The lost wax technique could be a solid cast or hollow-casting technique.

The method is quite simple. First, a model of the statue is created with clay and covered with wax in the case of hollow casting (McArthur, Taylor, and Craddock 2015, 112-113) and (Mertah 2021: 84) or wax only in the case of solid casting; then, the model is covered with material all around to create the mold. The mold must dry, and after removing the wax from the inside with fire, the model is taken upside down, thus obtaining the 'negative' into the cast (McArthur 2015: 112-113).

Next, the framework is filled with molten bronze, and the metal passes through small tubes, at the top or bottom of the cast. In this part, the liquid material goes in, melts the wax if it is not removed in advance, and takes on the desired shape, creating a hollow statue (McArthur 2015: 112-113).

Once the metal has cooled, the mold is removed. The last touches are made to the statues such as polishing metal, painting, or patination (McArthur 2015: 113-14). Sometimes, the core was left, and the residue of clay can be found on the core of the statues nowadays (Figure 18).

Hollow casting is the process used for the statue studies here. This process was generally used for larger works because it is an effective way of saving materials and reducing the cost of production. It consists of a mold of the statue created which then is cast in bronze (Mertah: 2021: 78).

The Technique of Gilding

As mentioned above, the statue was at least partially gilded. The technique of gilding is a very ancient technique, attested throughout the whole Egyptian history, on various categories of objects.

Gilding surely had an aesthetic goal but was probably also a way to provide a divine appearance to the objects, since the flesh of deities was supposed to be made of gold. In the corpus of statues of Osiris, it is not uncommon to find traces of gold leaves. Statues of the god were apparently often gilded, either on their entire surface or on specific parts.

The main method of gilding during the Pharaonic period was leaf gilding; this way of gilding involved applying a gold leaf to the surface of the object using an adhesive as a merger. Different types of adhesives were used such as egg white or Arabic gum. Another way of adhering to the gold leaf was using a preparation layer of calcium (Hatchfield 2011: 28).

Usually, objects made using this technique were polished to create a shiny surface. The strong presence of calcium carbonate in the white layer above the metal suggests that gilding was carried out using this technique.

5. Diagnosis of the Conservation State

Damage Map

The map in Figure 19 shows the various forms of deterioration of the object. In our case study, the main concern is the presence of encrustations of dirt, traces of active corrosion on both sides, and cracks especially on the lower part, which are endangering the statue's state of conservation.

Corrosion processes are responsible for the formation of cracks and microcracks. The loss of metal in certain parts, such as the head and feet, occurred intentionally before burial. In the case of gilding and decorations, very little is left. The most significant presence of gilding is on the upper part of the statue, on the scepters, and around the neck.

In conclusion, the statue was in a poor state of conservation, and a conservative intervention was needed.

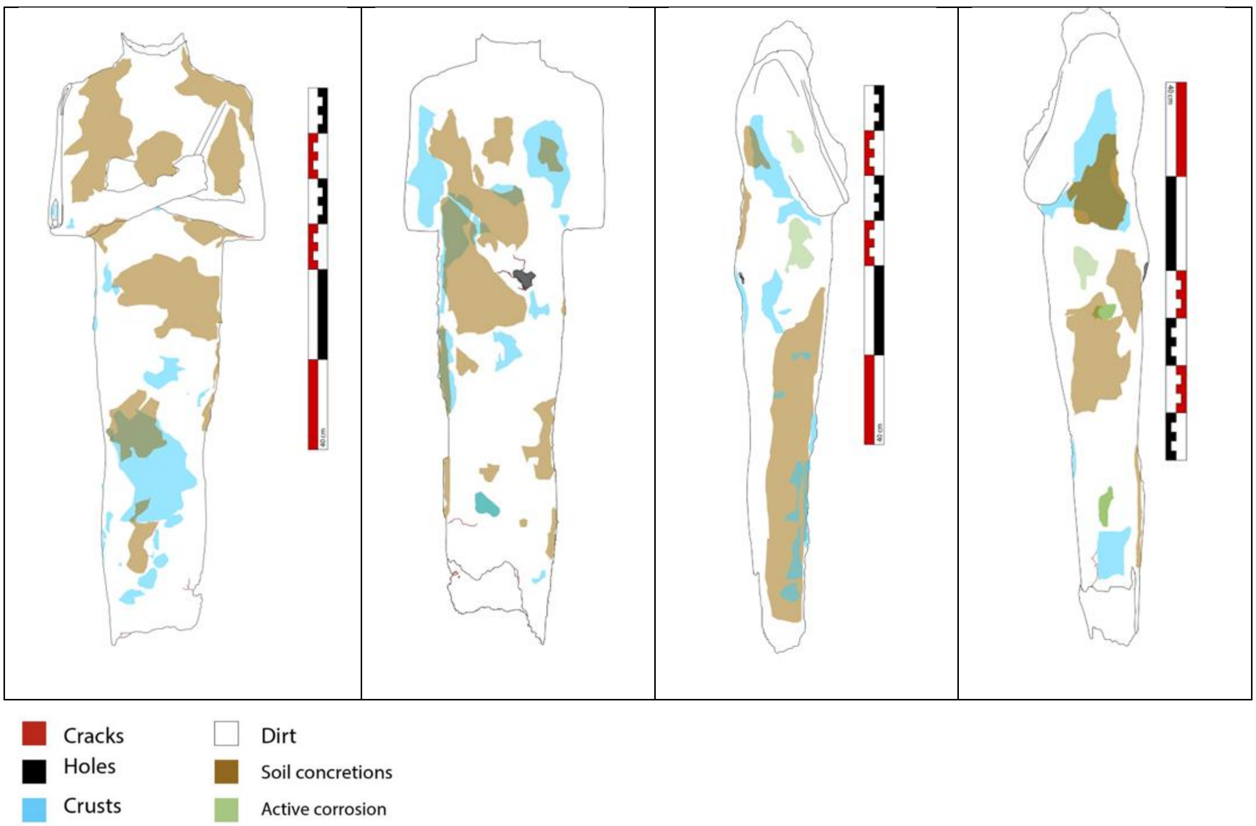

FIGURE 19: Damages map.

6. Restoration Process

6.1. Preconsolidation

Preconsolidation of the statue was a crucial stage before the cleaning process, as the statue presented very weak parts, especially in the lower part which included cracks and microcracks. Consolidation of some layers containing tiny remains of gold was carried out step by step during the restoration process to preserve these traces. Consolidation was achieved by injecting a 3% solution of PARALOID B44 into a mixture of acetone and ethyl alcohol (1:1). The same process was applied to both sides of the statue.

6.2. Mechanical Cleaning

The cleaning process of an object can be carried out by mechanical or chemical methods. The difference between the two is that, for the former, different tools or even surgical instruments are used to help remove the remains that do not belong to the object, while chemical cleaning is used for the removal of difficult conditions and is powered by the use of different chemicals and solvents (Abdelbar 2021: 1415-1416).

In our case, it was decided to use only mechanical cleaning. Studies have shown that chemical cleaning could affect the degradation state of the object, while laser cleaning offers a range of exposure parameters where selective removal of dirt is possible, avoiding the use of laser cleaning over tiny remains of gold (Lee 2013: 237).

The cleaning process starts with the removal of soil and dirt concretions using the softest tools. To remove the crust and corrosion, different kinds of brushes were used, from the softest to the hardest. Subsequently, an ultrasonic pen and micromotor devices were used, depending on the thickness or hardness of the concretions to be removed (Abdelbar 2021: 1415-1416; Ghoniem 2014: 46-47). On the crusts closer to the cracks, particular care was taken. Once all the crusts had been removed, a final general cleaning was carried out using micro fiberglass pens and scalpels (Figure 20).

Laser Cleaning

An Nd YAG laser system was used to perform the final cleaning process. Laser cleaning intervention on archaeological metals is becoming more common nowadays because it allows selective cleaning and is noninvasive, eco-friendly, and contactless, in short amazingly effective on archaeological bronzes (Lee 2013: 237). Laser cleaning has been shown to be very effective in removing corrosion without damaging the original surface (Rotondi 2023: 189). Preserving the shape of the metal, laser cleaning was applied as the last phase after the chosen mechanical intervention (Rotondi 2023: 192).

FIGURE 20: Statue after mechanical cleaning.

The main problem with bronze objects is the active green layer of corrosion on the surface, due to the interaction of the artifacts with the soil and other atmospheric and environmental parameters such as humidity and temperature.

Different wavelengths and energy radiations (Hz) were used to determine the best formula for cleaning the corrosion from the surface. Table 3 shows the frequencies used during the study.

TABLE 4: Parameters and laser trials.

	Wave-length nm	Pw	Hz	Results
Trial 1	266	125	20	No
Trial 2	266	150	20	No
Trial 3	355	200	20	No
Trial 4	532	200	20	Good
Trial 5	532	200	10	Good
Trial 6	1064	200	10	Good

Six tests were carried out. The lowest radiation energy (125, 150, and 200) with the wavelengths 266 nm and 355 nm proved too low. Increasing the power and wavelength gave remarkable results, eliminating all the remaining green corrosion (Korkmaz 2022: 76-77).

Subsequently, a study of laser cleaning of the statue's surface with the help of a digital microscope was made. It was determined that the best approach to remove the last level of oxidation was to use a wavelength of 532 nanometers, a power of 200, and a beat of 20Hz at the beginning and a pulse of 10Hz for the final pass. Using a wavelength of 1064 nanometers, a power of 200, and a beat of 10Hz was also found to be very effective (Lee 2013).

FIGURE 21: Surface before laser cleaning under the microscope.

Even though the laser gave very satisfactory results in eliminating the corrosion without affecting the original surface, copper corrosion still remained around the object due to the surface pits, and the inhomogeneity of the corrosion layers (Figures 21 and 22) and these still had to be removed by hand using a scalpel and needle.

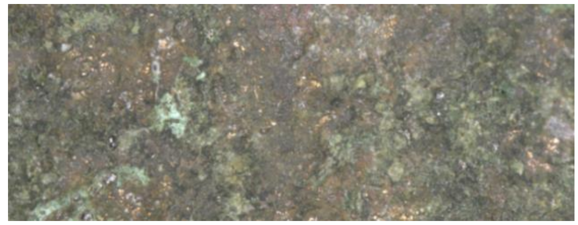

FIGURE 22: Surface after laser cleaning, by using a wavelength of 1064 nanometers, a power of 200, and a beat of 10 Hz.

6.3. Consolidation and Protection

For the final process, the object will be consolidated with PARALOID B44 at 3% in alcohol and acetone for cracks and microcracks in order to stabilize the structure (following Machuca et al. 2020: 29)

Finally, active corrosion will be neutralized in the corresponding areas with Benzotriazole, to prevent it from spreading to other areas.

7. Preventive Conservation Proposal

Preventive conservation is a fundamental part of ensuring that the object retains a good state of conservation after conservative intervention.

Therefore, it is essential to individuate the risks associated with the conservative environment that may compromise the state of conservation of the object, and the possible solutions to prevent deterioration of the object.

To this end, a study of the environment where the object will be displayed or stored is crucial, and adequate environmental parameters must be indicated (Bigi 2019: 32–37; Herráez 1999: 146).

In conclusion, indirect conservation makes it possible to avoid or minimize the action of loss or deterioration of the works of art.

7.1. Humidity and Temperature

Humidity and temperature are the most serious problems a metal object must face; the ideal humidity for an object like a bronze statue is between 45 and 55% HR. But in our case, given that active corrosion is existing on both sides and on the back, the drier the atmosphere, the better, without exceeding 45% humidity. The statue was in a poor state of conservation due to the exposure during the burial period: moisture coming from the ground has affected the corrosion of the object and could lead to its disintegration or fragmentation. The ideal temperature should be between 18 and 22°C (Diban 2020: 183).

7.2. Light Pollution

The radiation associated with light can trigger physical and chemical degradation processes due to photochemical processes. This is why a study of the environment of the object must be done as well as a good lighting plan. It can be estimated that this type of archaeological object can tolerate around 300 lux and 600 k/lux per year (De Andrés 2003: 89-90).

8. Conclusions

The contextualization of the work has been essential for the approximate dating and the knowledge of the statue, as well as the understanding of its function within its environment.

The iconographic and technical study has helped us to understand the significance and intentionality of the work and its compositional materials.

The photographic and radiological recording and study have been essential for the identification of the degradation layers and processes that could not be seen with the naked eye, as well as the discovery of the interior structure of the object.

Cleaning was conducted in accordance with the main objectives, using eco-friendly systems such as mechanical cleaning and laser cleaning. The cleaning process allowed us to discover the decoration remains of gold foil, Egyptian blue, and lapis lazuli inlays (without damaging the original patina and helping us to reconstruct the statue's original appearance).

The object is now ready in the restoration lab to be displayed for the first time to the public.

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