# A Multianalytical Study of an Ancient Egyptian Mirror at the Grand Egyptian Museum

**Almoatzbellah Elshahawi**

Egyptian Museum in Cairo, Ministry of Tourism and Antiquities, Cairo 11566, Egypt

## Abstract

This paper will present the results of a multianalytical study on an ancient mirror disk stored at the Grand Egyptian Museum (GEM). The metal mirror disk was discovered at the Tura El-Asmant archaeological site in the governorate of Cairo, Upper Egypt, dating to the Late Period. The mirror is in poor condition and covered with corrosion layers which required suitable conservation treatments in order to preserve and display it in the GEM. The primary goals of the study are to identify the various types of corrosion and deterioration that have degraded the mirror in order to determine the most suitable method for the conservation. The study uses many techniques, including scanning electron microscope (SEM), radiography, metallography examination, and portable X-ray fluorescence, which allows compositional analysis and gets information about the technique used to produce it. The mirror's past, present, condition, documentation, conservation techniques, preservation, and storage recommendations will be explored in this contribution.

*Keywords*: Symbolism, Tura El-Asmant, Egypt, Late Period, corrosion, conservation, inhibitor
*DOI*: 10.31526/SEAS.2025.532

يتضمن هذا البحث نتائج دراسة تحليلية متعددة لمرآة فلزية قديمة محفوظة بالمتحف المصري الكبير. تم اكتشاف المرآة الفلزية بموقع طره الأسمنت بمحافظة القاهرة، والتي يعود تاريخها إلى العصر المتأخر. المرآة في حالة حفظ سيئة ومغطاة بطبقات من التآكل مما يتطلب التدخل بمعالجات الحفظ المناسبة من أجل الحفاظ عليها وعرضها في المتحف المصري الكبير. الأهداف الأساسية للدراسة كانت التعرف على أنواع التآكل والتلف المختلفة التي أدت إلى تدهور المرآة من أجل تحديد الطريقة الأنسب للمحافظة عليها. استخدمت الدراسة العديد من التقنيات، بما في ذلك المجهر الإلكتروني الماسح، والتصوير بالأشعة السينية، وفحص التركيب البنائي، والتحليل بواسطة إستخدام تفلور الأشعة السينية المحمولة، مما يسمح بالتعرف على مكونات سبيكة المرآه والحصول على معلومات حول التقنيات المستخدمة لإنتاجها. سيتم استكشاف السياق التاريخي للمرآة وحالة حفظها وتوثيقها وتقنيات الحفاظ عليها وتوصيات الحفظ والتخزين في هذه الدراسة.

الكلمات المفتاحية: رمزية، طره الأسمنت، مصر، العصر المتأخر، تآكل، حفظ، مثبط

## 1. Introduction

Mirrors were very popular in Ancient Egypt. If not earlier, the Old Kingdom (3rd through 6th Dynasties; circa 2675–2170 BCE) is when the Egyptians first began to use mirrors (Lilyquist 1979: 47–77; Bénédite 1907: 81–88). The copper mirror (case study) was at the Atfih Storerooms and then moved to store at the Grand Egyptian Museum-Conservation Center (GEM-CC) with the accession number GEM. No. 40220 and dates to the Late Period (664–332 BCE). It is 13.04 cm high, 12.7 cm wide, and 4.54 cm thick and weighs 264.4 g. The mirror is in poor condition, and its whole surface was covered with corrosion layers which required suitable cleaning and conservation treatments. It was discovered in the Tura El-Asmant site, located about halfway between Cairo and Helwan (Figure 1). The site was very important in antiquity when it was the primary quarry for limestone in Ancient Egypt and one of the important centers of Early Dynastic funerary activity (Nicholas 1988: 27, Charlton 1978: 128).


**FIGURE 1:** Tura Al-Asmant Location Site © Google.

Degradation occurs, when objects are made and when they react to archaeological burial and continue till post-excavation conditions. As a result, the majority of excavated copper artifacts are covered in corrosion products and lost their original colors and their shiny surfaces like in the case of the studied mirror. More importantly, understanding the production techniques and corrosion characteristics of these artifacts is crucial for proper artifact preservation (Cho et al. 2021: 1–15).

Artifacts made from copper and its alloys buried for a long time eventually corrode, changing their morphology to a stable state and forming different corrosion products. Typical copper corrosion products include cuprite ($Cu_2O$), tenorite ($CuO$), malachite ($Cu_2CO_3(OH)_2$), and paratacamite ($Cu_2Cl(OH)_3$). Here, various factors, including the artifact's composition, manufacturing technique, size, and burial environment, have an impact on the type and shape of the corrosion products. Furthermore, based on the corrosion products and varying conditions, the burial environment can be inferred (Scott 2002: 35–40). Also, to properly evaluate the studied copper disk mirror, it is important to consider factors like metallurgy, corrosion, and encrustations. This can provide beneficial insights regarding the preservation condition of the object and information for the proper treatments (Yokota et al. 2003: 268–276).

In this paper, the historical symbolism and representation of mirrors in Ancient Egypt will be discussed before summarizing the various scientific investigations carried out on this particular mirror.

## 2. History and Symbolism of Mirrors in Ancient Egypt

Egypt is appropriately regarded as one of the origins of mirror-making. Although there is no evidence that metallic mirrors existed in Predynastic Egypt, researchers have found objects in the burials of the so-called Badari culture (c. 45000–4500 BCE) that might be the earliest examples of manufactured mirrors. They were polished disks made of a highly polished selenite flake put into a wooden frame that has been dated to the Badarian age showing an incredible skill in the creation of this early prototype (Lilyquist 1979: 78–82, James et al. 2000: 31–41). Such early mirrors were probably employed not just as cosmetic items but also as ritual objects, symbolizing deities, and they were probably not utilized as mirrors in the modern sense (Mahran et al. 2016: 11–13, Pendergrast 2004; 245-246). They were used to be buried with the dead, close to their hands or feet, as one of the funeral objects (see Figure 2). This practice persisted in a significant fashion until the Second Intermediate Period. However, with the beginning of the Third Intermediate Period, mirrors appeared less frequently among funerary items.

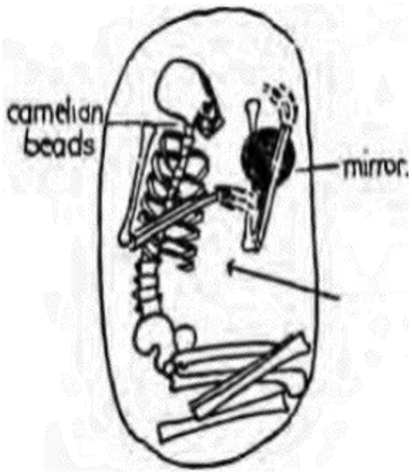


**FIGURE 2:** Buried Egyptian Male and the mirror, between upper left and lower left arm (Reisner et al. 1908).

Only one mirror that belongs to Hor-Nakht was found in Tanis' royal cemetery as proof of this tradition (Anderson 2007: 1–15).

Egyptian mirrors also were associated with Hathor, the goddess of love, fertility, beauty, and dance. Hathor was usually represented as cow-headed, her horns enclose a sun-mirror disk, and she was identified as the eye of the sun god. Perhaps, this is why some Egyptian mirror representations have magical eyes painted in their center. The *ankh-sign*, the Egyptian symbol of life, looks like a mirror; it is shaped as an egg, with a T-handle attached at the small end. The long name for the mirror is ankh-en-maa-her, potentially meaning something like "life-force for seeing the face," and was shortened to "see-face" (Lilyquist 1979: 83–89; Bianchi 1985: 10–18; Coşkunsu et al. 2019: 1–7).

Mirrors frequently played a cultic role in Egypt and were presented as dedications, with their circular reflected surfaces thought to symbolize the sun (Thomas and Acosta 2017: 1–30). Mirrors have been linked to Hathor throughout Egyptian history and Aphrodite during the Greco-Roman era. Mirrors had both practical function and religious connections to both the Sun God Ra and Hathor the goddess of love and beauty (Thomas and Acosta 2017: 1–30; Backhouse 2021). Ancient Egyptians and many other ancient peoples interred their dead with metal or stone reflectors in order to keep the soul, ward off evil spirits, or allow the body to inspect its look before making the final journey to the afterlife (Anderson 2007: 1–15; Pendergrast 2004; 245-246; Stoneman 2016: 239–243).

Among the objects that were represented under the chairs on the tombs were mirrors. Depictions of mirrors under the chairs of men accompanied by other objects are to be seen during the Sixth Dynasty. They were used to serve personal purposes and religious ceremonies in the afterlife (Mahram et al. 2016: 11–14). Mirrors made of polished metal have been found in the Sixth Dynasty (c. 2345 BCE) tombs. Also, in New Kingdom tomb scenes, mirrors are frequently placed under the chairs of women, as well as in scenes from men's tombs (Bianchi 1985: 10–18; Coşkunsu et al. 2019: 1–7).

Symbolism and representations of mirrors are usually accompanied by inscription. For those reasons, associated objects are not often important in establishing the date of the mirrors (Lilyquist 1979: 79–89). Therefore, it is challenging to interpret the symbolism and representation of the copper mirror under study because it lacks inscriptions or has faded as a result of deterioration (Figure 5).

## 3. The Manufacturing Techniques of Ancient Egyptian Mirrors

As mentioned above, mirrors made of polished metal have been found in the Sixth Dynasty (c. 2345 BCE) tombs. Many of them had forms that suggested they might have had handles made of wood or ivory (Coşkunsu et al. 2019: 1–7; Enoch 2006: 775–781).

Mirrors gradually advanced in sophistication, adding an elaborate handle and a well-rounded metal disk that is highly polished. The handle of the mirror was made of wood, metal, or ivory (Lilyquist 1979: 41–47; Chavez 2010: 23–26). The first mirrors were made of copper dated around 2900 BCE. Then, later ones were composed of tin and copper alloys (bronze), and ultimately silver and gold were added (sometimes, although rather rarely, they were entirely made from silver).

Mirror manufacturing processes evolved during the New Kingdom and Late Period, as evidenced by numerous diverse shapes that differed from the conventional upside-down pears with handles shape that was prevalent from the earliest times until the end of the New Kingdom.

A few were slightly convex or concave, polished on both sides, and somewhat elliptical (wider than high) with a sharp metal tang at the bottom that fit into a handle made of wood, stone, ivory, horn, metal, or clay. Cloth, animal hide, or woven rushes were used as coverings for the highly polished surface (Pendergrast 2004: 245-246).

Egyptian mirrors generally consist of three parts. The mirror disk could have been made of highly polished copper or bronze alloy but sometimes gold and silver. The disk is usually flat and has a sharp tang in order to connect it to a handle. An umbel, usually in the shape of a papyrus flower, connects the mirror disk to the handle which is normally made from wood, ivory, bone, or metal alloys (O'Neill 2011: 1–16). There was a mirror in Tutankhamun tomb housed in a specially made wooden box, which was inlaid with colored glass, carnelian, and quartz and embossed with sheet gold (Carter No. 269b). The typical oval disc was replaced by a circular form during the Eighteenth Dynasty. There were many different shapes for handles, including those of animals, adolescent girls, and papyrus flowers (Mahran 2011: 11–33; Bianchi 1985: 10–18; Elhosary 2022: 130–133). As for the producing techniques of the ancient mirrors, they were made by solid cast in a single piece (Scott 2014: 67–90).

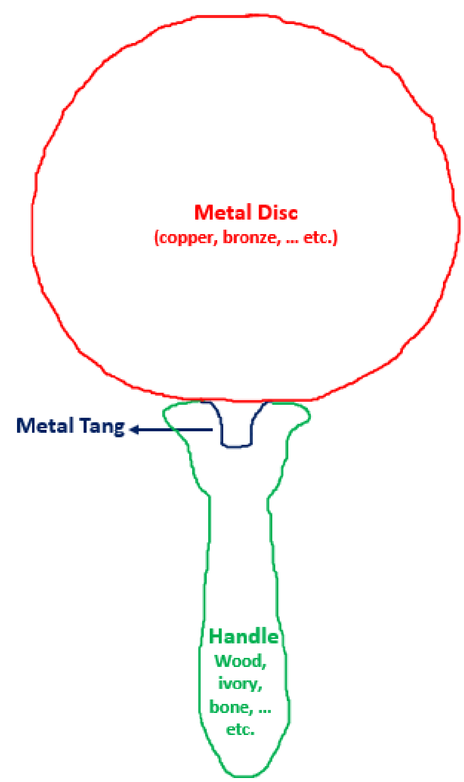


**FIGURE 3:** The parts of a typical ancient Egyptian mirror (by the author).

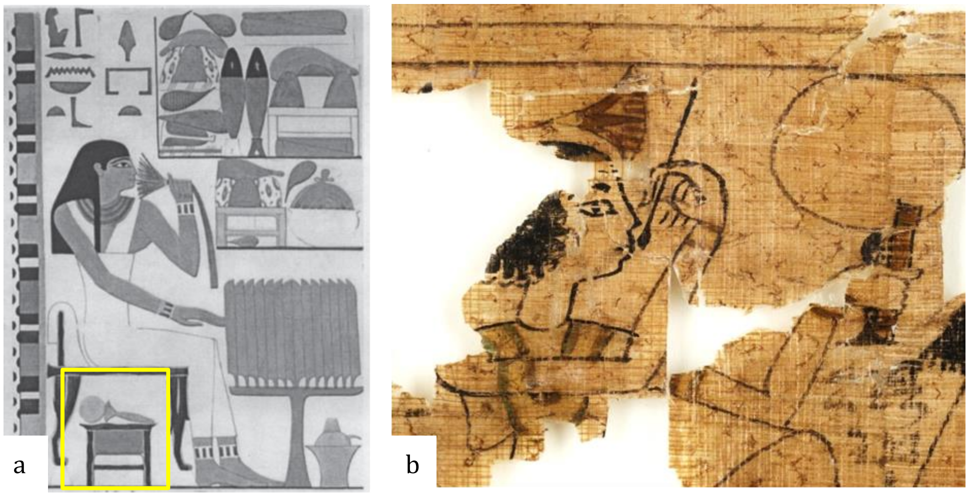


**FIGURE 4:** (a) Mirror under the chair of the wife of Tjetu I "5th-6th dynasties" (Mahran & El-Kilany 2016). (b) A scene from Turin papyrus showing a lady holding a mirror. Cat. 2031. http://collezioni.museoegizio.it/ (Accessed 23.02.2023).

# 4. Materials and Methods

## 4.1. State of Preservation of the Mirror

The studied object is an Egyptian copper disk mirror (GEM No. 40220, in storage, inorganic lab, Grand Egyptian Museum). It was discovered at the Tura El-Asmant site, Lower Cairo, Egypt, and is dated to the Late Period. It is slightly oval in shape, with a tang for handle attachment (wooden or metallic). There are similar examples in many different museums, for example, a mirror on display at Bristol Museum & Art Gallery, Egypt Gallery (accession no. H19), and two mirrors at the Royal Museums of Art and History (RMAH) collection, Belgium (accession no. E.01969 and E.04267) (Rademakers et al. 2021). It is undecorated and in poor condition. The whole surface of the mirror disk is heavily encrusted with corrosion products, soil deposits, and encrustations. Corrosion products and encrustations are present and display different colors (white, red-brown, black, greenish blue, light-green, and green) covering both sides of the mirror, which is typical for ancient Egyptian copper and copper alloy objects. The handle of the mirror is missing (Figure 5).

## 4.2. Documentation

The physical deterioration and corrosion products of the copper disk mirror were documented and mapped using AutoCAD, and the corrosion products were identified based on X-ray diffraction analysis. This helped in assessing the current condition of the studied object, emphasizing areas of weakness and active corrosion that needed immediate treatment, which has since been addressed. It also helped to distinguish the overlap between the corrosion compounds and deterioration aspects, such as cracks, incrustations, and stains. Each aspect and corrosion product were characterized with a specific color or symbol, red-brown (cuprite), green (malachite), light green (copper chlorides/atacamite), black (tenorite), and beige (soil deposits) (Figure 6).

Most soils do allow corrosion due to the presence of oxygen. In contrast, in the soils of an anoxic condition, it prevents the formation of corrosion products.

Based on the corrosion products formed on the surface of the uncovered artifacts, it could determine the nature of the soil and environment from which the objects came (Scott 2020: 39–53; Ingo et al. 2006: 513–520). The presence of cuprite, malachite, and atacamite was confirmed by X-ray diffraction analysis concluding that the soil contained high chloride content and high quantities of organic materials (Scott 2002: 100–125).


**FIGURE 5:** The copper disk mirror (case study).

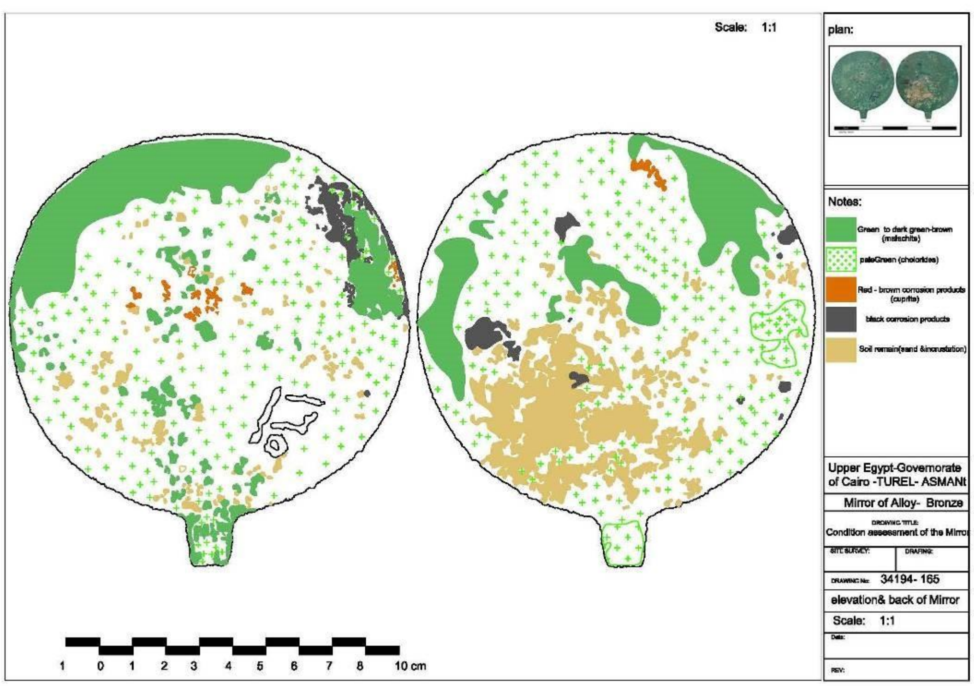


**FIGURE 6:** Documentation of the deterioration aspects and corrosion products of the copper mirror using the AutoCAD program.

The analytical techniques selected to conduct this investigation are based on the suitability for characterizing metal object materials. Therefore, the instrument parameters must meet conservation standards regarding sampling, where minimum or no samples should be taken from artworks: Stereo Microscope, X-radiography, scanning electron microscope (SEM), Metallographic examination, portable X-ray fluorescence (pXRF), and X-ray diffraction (XRD).

### 4.3. Multispectral Imaging

Ultraviolet light, as provided by a VISTA UV HANDLE H.F lamp with 360 nm wavelength emission, was used to illuminate the mirror in order to detect any organic residues, resins, or adhesives or modern restoration evident on the mirror. Visible-induced infrared luminescence (VIL) using a Sony A6000 digital camera modified to "full spectrum" with a 90C IR Filter and a LED lamp to view the fluorescence (luminescence) was used in order to identify structural inhomogeneity in the manufacturing technique of the mirror and to receive a VIL imaging of ancient pigments remains on the surface such as Egyptian blue.

### 4.4. Stereo Microscope

Microscopical investigation was performed on a ZEISS Stereo Discovery V20-AxioCam MRc5 in order to evaluate the condition of the disk mirror and to understand the nature of surface and corrosion products (Odler et al. 2020; 241).

### 4.5. X-Radiography

The mirror was photographed with portable X-radiography (Radioflex RF-200SPS) to examine the surface morphology and understand the casting features. Radiographed image was captured at 80 kV, 2 mA, and 6 second exposure (Figure 8).

### 4.6. SEM

A scanning electron microscope (SEM; FESEM/Quanta FEG 250, MADE IN NL) was used for structural observation and to assess the metal and its corrosion. Images were obtained at 30 kv with working distance of 12.4 and 12.5 mm. *SEM* images indicate not only the distribution of copper but also its particle size.

### 4.7. Metallography

A small discrete sample was taken from area already damaged (debris) during excavation. It was mounted with an epoxy resin (araldite 2020) for metallographic study and polished using silicon carbide grinding pads (300, 500, 1200, and 2000 grit) with water-based suspensions on a microcloth pad. The sample was etched with a 3% ferric chloride ($FeCl_3$ + HCl + ethyl alcohol) solution for 2 to 3 seconds during the final step according to ASTM E407-07. Meanwhile, the microstructural observation was performed using an Olympus PMG-3 Metallographic Microscope restored (Ingo et al. 2006: 513–520; Scott 2014, 67–90).

### 4.8. p-XRF

A handheld Bruker Tracer Spectrometer (Alloy Modes: Metal Alloy, Electronics Alloy, Precious Metals, 40 kV high voltage, 20 A anode current, 40 seconds live time irradiation) at the GEM-CC was used as a noninvasive method to provide broad insight of the surface elemental composition via spot testing.

### 4.9. XRD

A sample of the corrosion products was examined with X-ray diffraction (XRD) at GEM-CC to better understand the components of the corrosion layers and their nature. The corrosion sample was ground using an agate mortar for obtaining 5–10-micron grain size. The X-ray diffractometer system (PANalytical, X'Pert Pro, PW 3040/60 model) was used, with a Cu anode, working at 30 mA/40 kV at a 25°C with a step size ($2\theta$) of 0.033. An X-ray tube produced a monochromatic Cu K$\alpha$ radiation of wave length 0.154 nm, recorded from ($2\theta$) 5° to 70° in the case. Samples were grinded using an agate mortar for obtaining 5–10-mi-cron grain size. X'Pert high score data acquisition and an interpretation software (Malvern PANalytical, Malvern, UK) were used for interpreting the results.

## 5. Conservation and Preservation Processes

### 5.1. Active Corrosion Test

The silver nitrate chloride spot test was used to assess active corrosion prior to treatment. Minute samples were taken from areas exhibiting powdery bright green corrosion. The samples were put on a glass slide, and then a drop of 2.5% nitric acid (in deionized water) and a drop of 3% silver nitrate were each added (in deionized water). The appearance of a white precipitate suggests the presence of chlorides and, thus, active corrosion (Scott 2020: 39–53; Laver 1978: 1–11; Riss 1993: 1-2).

### 5.2. Temporary Consolidation

To prevent the mirror from additional damage brought on by the pressure of the mechanical cleaning process, one side of the mirror was initially supported with thin strips of Japanese tissue attached with 0.5% of Klucel-G (hydroxypropyl cellulose) in ethanol by brushing (Figure 7). The weak parts were consolidated with paraloid B-72 3% in acetone by brushing. The same process was done on the reverse side of the mirror.

**FIGURE 7:** Appling a facing layer using tissue Japanese paper with 0.5% of Klucel-G in alcohol as a temporary consolidation/support of the copper mirror.

### 5.3. Surface Cleaning

The cleaning process to get rid of any incrustations and corrosion products was chosen based on the condition of the copper mirror. All mechanical cleaning was done following conservation guidelines (Rifai et al. 2023: 26–33; Koh 2006: 1–4).

### 5.4. Coating and Stabilization

Due to the mirror's poor preservation state and the presence of active corrosion, a corrosion inhibitor in addition to a protective coating layer had to be applied.

# 6. Results and Discussion

## 6.1. Characterization and the Condition of the Mirror

According to visual observation and microscopic investigation, the mirror is covered in a thick layer of encrustations, soil deposits, and corrosion products, which disguise any ornamentation that may be on the surface of the mirror. The corroded layer and encrustations have a varying surface morphology and texture; in some areas, it is loose and less thick; in others, it is compact. The surface is covered with corrosion products and soil deposits. The mirror's surface is distinguished by a rough, corrosive surface and pits with a variety of corrosion products in various colors, including dark green, light green, greenish blue, and white-gray surfaces covered in soil residues. Moreover, some areas present active corrosion, further demonstrating the corrosion process' ongoing progression (Pollard et al. 1989: 557–563; De Ryck 2004: 189–195).

Sand and soil deposits found on the surface of the mirror indicate the type of soil and environment in which it was buried, which is consistent with the type of soil and environment at the Tura Al-Asmant site, being sandy desert soil.

## 6.2. Stereo Microscope

Microscopic images showed that the corrosion products and soil deposits are a complex formulation that includes numerous ingredients. The different patina layers and areas where original surface remains could be distinguished using a stereo microscope. In addition to the soil deposits, photomicrographs show various colors of corrosion products on various areas of the mirror's surface (Figure 8) (Weichert 2004: 149–159; Figueiredo 2010: 13–28).

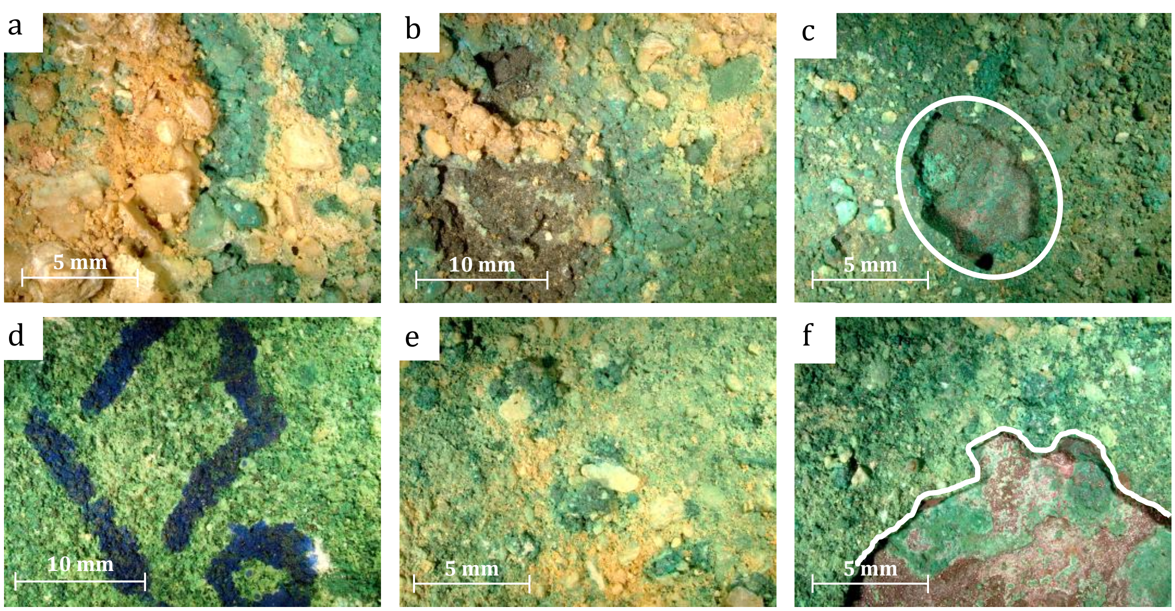


**FIGURE 8:** Encrustation under higher magnification showed quartz crystals and soil deposits (a, b). Complex, uplifted green, and light green corrosion on the surface of the mirror indicates active corrosion (atacamite) as confirmed by XRD, and area of flaking (c). An accession number of the mirror is written directly on the surface of the mirror (d). Different forms of corrosion and soil deposits (e). Red cuprite corrosion and an area of flaking (f).

## 6.3. X-Radiography

Radiographs demonstrated the mirror's structural integrity and confirmed it was solid cast. The casting of the mirror might have a flaw, the lighter areas show where the metal is more stable and complete, and the darker patches reveal areas of imperfections. For the purposes of this study, the term of "black fibers" will be introduced which is unexpected and unusual phenomena that have not seen before on copper objects investigated using radiography. Since these fiber formations are very radio-transparent, these areas represent places where the metal is actually missing or very thin. Since most are around the edges, my hypothesis is it may be a corrosion process resulting from metalworking stresses. These stresses provide areas of increased corrosion rates. The branching fibers may represent metal that has been converted to corrosion products, following crystal boundaries formed during the cooling pace as part of the production process, or the "stretch-patterns" in the metal from cold shaping. This hypothesis is supported by the visible corroded area appearing in the reverse photo that seems to correspond to the centralized knot of dendrites in the X-ray (Figure 9). Another hypothesis is that this object is made using a solid cast technique which often has a secondary work performed by hammering which caused these black fibers (Scott 2002: 318–334).

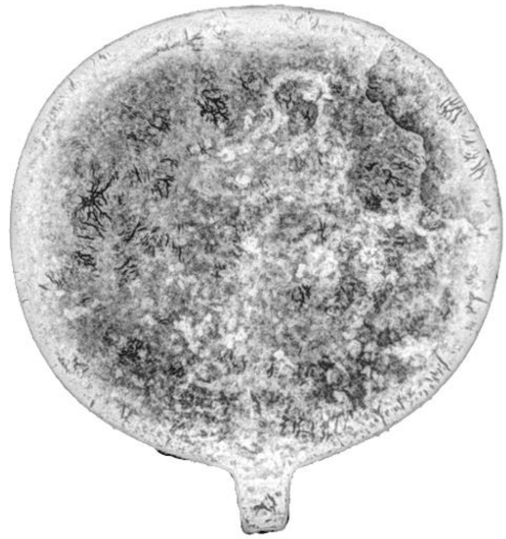

**FIGURE 9:** Radiography of a mirror, revealing only minor casting defects, small black fiber formations, and patches.

## 6.4. Multispectral Imaging

Ultraviolet and Visible-Induced Luminescence imaging did not indicate any presence of pigment remains on the surface of the mirror (Figure 10).

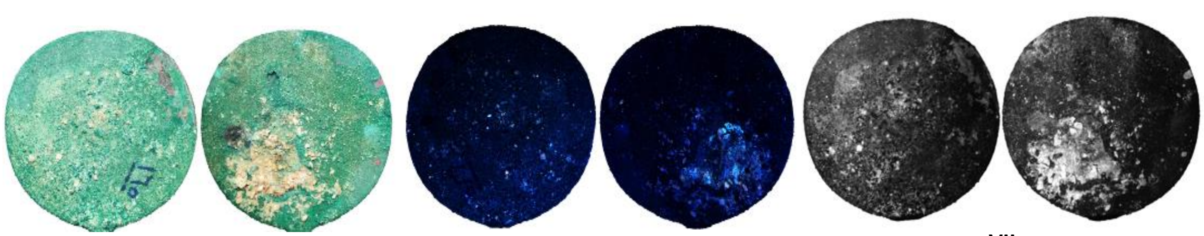


**FIGURE 10:** Detail of multispectral imaging. Normal light (left), ultraviolet visible fluorescence (UVF) (center), and visible-induced infrared luminescence (right).

## 6.5. Optical Microscope and Metallography Results

The mirror sample's metallographic analysis confirmed that there is an original metal structure (core) preserved between the altered layers. The black layer is clearly evident at the level of the original metal. This layer has only been identified visually. The results also revealed that the mirror alloy is characterized by hard crust and heavy corrosion layers. The corrosion products formed an inhomogeneous layer on the surface (Figure 11).

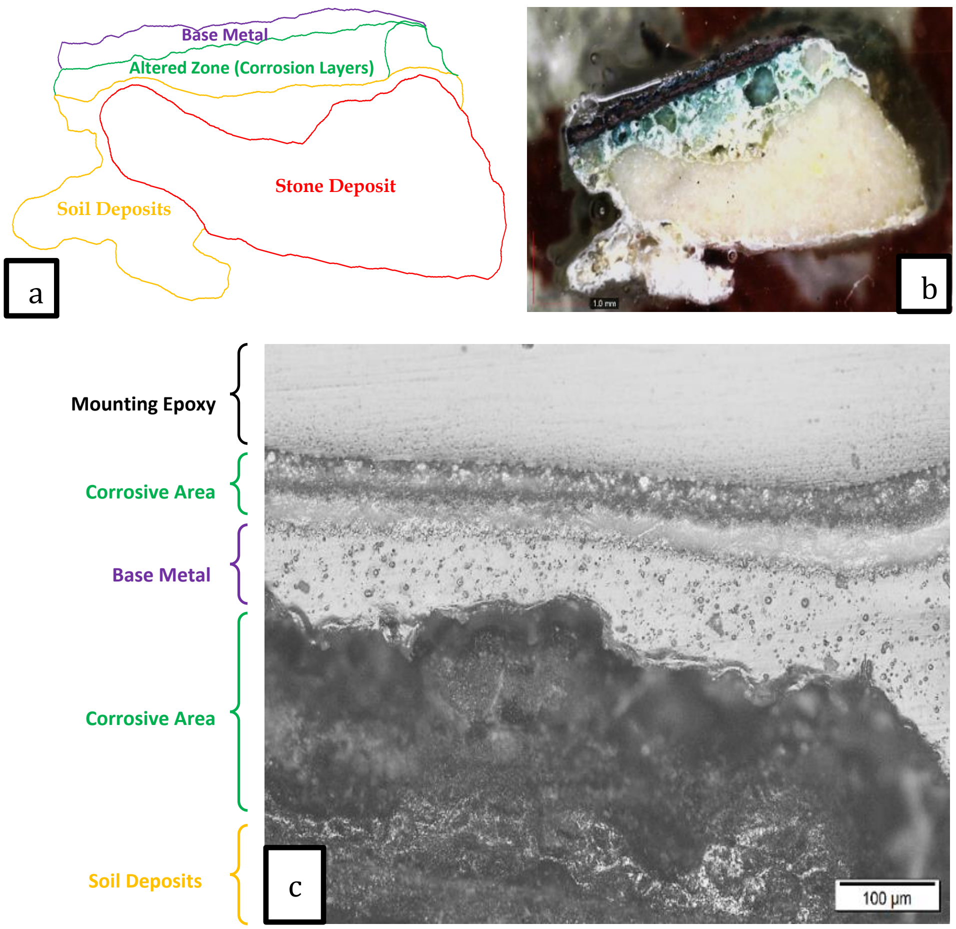


**FIGURE 11:** Optical micrograph of a cross-section of the ancient copper fragment. A mirror sample and its layers' facsimile (schematic illustrating) (a, b). Stratigraphy of the metal core and corrosion layers (c).

The formation of corrosion layers is typical for ancient copper with layers of $CuO$ and $Cu_2CO_3(OH)_2$.

## 6.6. SEM Results

Figure 12 presents SEM images (micrographs) of the corrosion layer and soil deposits samples, respectively. Results indicate that the corrosion layers on the surface of the mirror are nonhomogeneous and a bit thick.

## 6.7. XRF Results

It is important to recognize that due to the thickness of the surface corrosions and the low surface penetration of the pXRF, selected areas of the mirror's surface on both sides were cleaned mechanically until reaching the original surface. In addition, the mounted sample was analyzed using portable XRF. The sample components have been fully identified based on their molecular structure, and the results were quantified by obtaining the average value of the analysis for various elements.

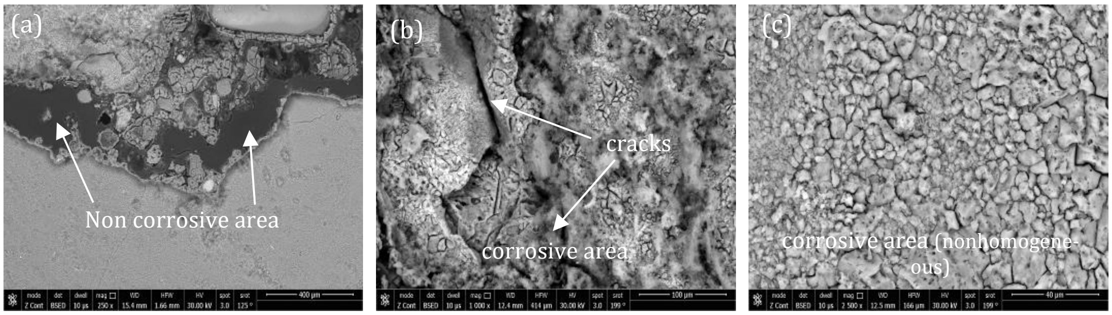


**FIGURE 12:** SEM images show the original microstructure without (a) and with nonhomogeneous corrosion and cracks (b, c).

The XRF results indicate that the mirror sample is composed of copper (Cu) with a variable trace of arsenic (As) and iron (Fe) (Table 1, Figure 13).

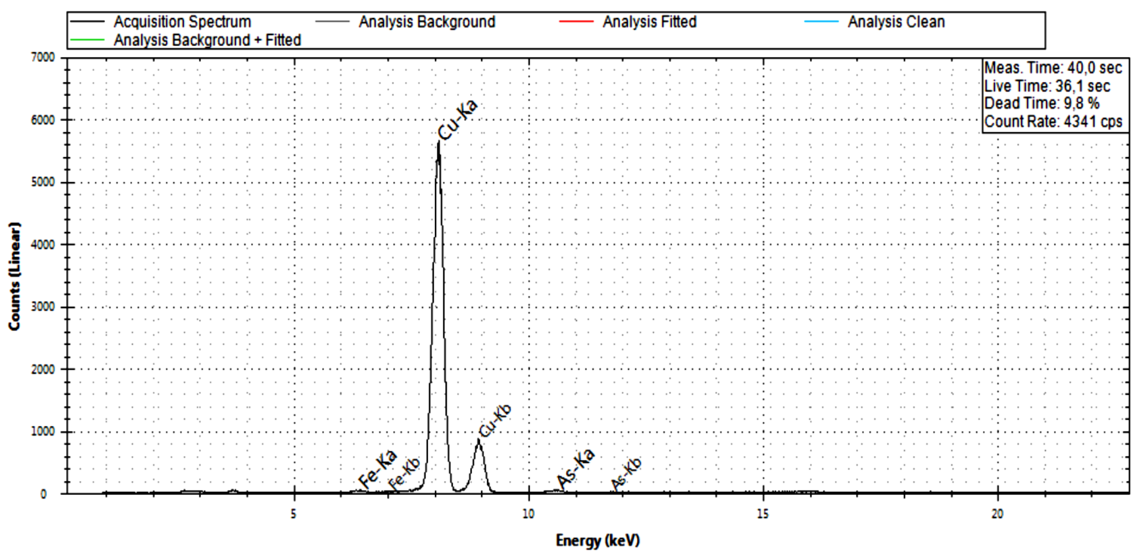


**FIGURE 13:** XRF spectra of the mirror sample.

**TABLE 1:** Elemental composition of sample using pXRF.

| | | | |
|---|---|---|---|
| **Elemental** | Cu | As | Fe |
| **Percentage (Wt.%)** | 97.97 | 1.63 | 0.4 |

Those additional trace elements apparent in the mirror are also seen in other ancient copper alloy artifacts. Arsenic and iron are regarded as impurities from the unrefined base ores accessed in antiquity. The presence of arsenic (deliberate or accidental) probably was to produce an alloy with a golden color and good hardening properties required to get a shiny mirror. In addition, it gives it properties similar to those of tin bronze, such as hardness and ductility (Scott 1991: 1–7; Odler 2016: 238–248).

## 6.8. X-Ray Diffraction (XRD)

The presence of sediments, soil deposits, and incrustation on the surface of the mirror gives a clear indication of the type of sandy and rocky environment in which the mirror was buried, which is mainly consistent with the soil and nature of the site of Tura Al-Asmant based on the author's observation. The XRD results also gave valuable insight into the corrosion layers. The use of XRD has revealed the presence of quartz ($SiO_2$), as well as copper species such cuprite ($Cu_2O$), carbonates like malachite ($Cu_2(OH)_2CO_3$), and atacamite ($Cu_2(OH)_3Cl$) (Table 2). This information provides evidence that the outermost corrosion layers are formed also through a strict interaction between soil constituents (Cl, Si, Ca, and $CO_2$) and metal corrosion products, primarily constituted of copper (Figueiredo 2010: 13–28).

**TABLE 2:** Corrosion products analyzed using XRD.

| Sample | Corrosion product | Chemical name | Chemical formula | Density g/cm$^3$ | Percent. % |
|---|---|---|---|---|---|
| copper corrosion products | Cuprite | copper (I) oxide | $Cu_2O$ | 6.1 | 15.4 |
| | Malachite | copper carbonate hydroxide | $Cu_2(CO_3)(OH)_2$ | 3.8 | 28.8 |
| | Quartz | silicon dioxide | $SiO_2$ | 2.65 | 26.2 |
| | Atacamite | copper (II) chloride hydroxide | $Cu_2Cl(OH)_3$ | 3.76 | 29.6 |

## 6.9. Conservation Processes

### *6.9.1. Cleaning Process*

Investigation and analyses have been useful in revealing minute features of the mirror's surface, elemental composition, and preservation condition. It also helped in understanding its alloy, as well as assisting in making good decisions regarding conservation plan and long-term care, and whether or not they should be subjected to proper conservation methods. Moreover, metallographic images made it easier to comprehend and track the layers of corrosion and their sequence, which in turn contributed in performing effective cleaning procedures without harming the original surface of the mirror, which must be preserved (Figueiredo 2010: 13–28).

Care was taken during the mechanical cleaning process to avoid scratching the mirror's original surface. Brushes, scalpels, micromotors, and ultrasonic pen (Woodpecker/DTE USD-P) were used to mechanically remove the corrosion products from the mirror's surfaces. A cleaned area was examined under a stereo microscope after mechanical cleaning (Figure 14). After removal, the following treatment involved the mechanical removal of the copper chlorides using a needle and a scalpel until bare metal was exposed. The excavated zone was then coated with a paste of silver oxide powder dissolved in ethanol, to fill the pits and arrest the active corrosion.

Following mechanical cleaning and visual observation, the surface morphology of the studied mirror started to appear. At this time, it was decided to forgo further cleaning procedures because the mechanical cleaning method had already produced the desired effects while protecting the cooper mirror's original surface.

During the cleaning process of the mirror, it was necessary to perform a temporary preservation procedure on the mirror in order to carry out the conservation process optimally because the study and conservation process took several months. The copper mirror was temporarily preserved by sealing it within an acid-free carton-board box to isolate it from the surrounding environment. Silica gel (100 g, transparent balls, pores diam. 4.5–7.0 nm nbsp) was placed inside the box (designed for mirror preservation) to keep the relative humidity below 35% (Figure 15).

**FIGURE 14:** Details of the corrosion layers and soil deposits on the surface of the mirror, and assessment of mechanical cleaning using a stereo microscope (left area before cleaning, and right area during/after cleaning).

**FIGURE 15:** Placing the mirror in an acid-free box with blue silica gel as a desiccant while undergoing conservation operations.

### *6.9.2. Stabilization and Coating*

Before applying the corrosion inhibitor to the mirror's surfaces, both of its faces were cleaned with alcohol to remove any dirt or dust. Using a brush, three layers of black seed extract (40 ppm) were applied to the mirror surfaces to prevent further corrosion and deterioration from environmental conditions while in storage at the museum.

**FIGURE 16:** Mechanical cleaning processes of the mirror using various tools.


**FIGURE 17:** The copper mirror before (a), during (b), and after conservation and removal of the corrosion products (c).

## 7. Conclusion

Identifying the preservation condition of the copper disk mirror required multitechnique analyses due to being covered with different corrosion layers and soil deposits. Advantages of each technique (SEM, pXRF, and XRD) were pointed out to present a broader knowledge of the preservation condition of the mirror and identify the nature of the deterioration aspects and the corrosion products. The black fiber pattern was unexpected, and an unusual phenomenon of the copper objects was investigated using radiography. As a result, this study hopes to serve researchers who specialize in the study of ancient metals to gain further insight into this phenomenon, interpret it in more detail, and establish connections between similar objects based on factors like producing technique, corrosion process, and the location of discovery.

Based on the results of the technical study of the mirror, it was necessary to remove corrosion layers and encrustations from the surface of the Tura Al-Asmant site mirror that was the subject of the study due to its poor preservation condition. To prevent corrosion and further deterioration processes, an extract of black seed at 40 ppm in alcohol was brushed over the mirror's surface as a green corrosion inhibitor.

In conclusion, this case study provides archaeologists, conservators, and conservation scientists with information regarding the composition and conservation methods applied to a copper mirror, applicable to other copper items from ancient Egypt.

## Acknowledgments

The author is deeply grateful to the ARCE for mentoring this research through Dr. Ashley Arico from The Art Institute of Chicago, for her invaluable advice.

### References

Anderson, M. (2207). *The Book of the Mirror: An Interdisciplinary Collection exploring the Cultural Story of the Mirror*. British Library Cataloguing in Publication Data, UK.

Backhouse, J. (2021). *Mirror Mirror: Ankh, The Image of Life*, The Explorers Club Events. Available at: https://themysteries.org/the-explorers-club [Accessed 1 May 2023].

Bénédite, G. (1907). Catalogue Général des Antiquités Égyptiennes du Musée du Caire, Miroirs. Le

Caire: IMPR. DE L'Institut Français D'archéologie Orientale.

Bianchi, R. (1985). Reflections of the Sky's Eyes. The University of Chicago Press on behalf of the Bard Graduate Center. Notes in the History of Art, Vol. 4, No. 2/3, pp. 10–18.

Bonati, I. and Reggiani, N. (2019). *Mirrors of Women, Mirrors of Words: The Mirror in The Greek Papyri*, Chapter 5. Mirrors and Mirroring.

Charlton, N. (1978). *Brief Communications: The Tura Caves*. The Journal of Egyptian Archaeology, Volume 64, The Egypt Exploration Society, London, p. 128.

Cho, N. Jang, M. Huh, K. (2021). *A Study on the Microstructure and Corrosion Characteristics of Early Iron Age Bronze Mirrors Excavated from the Korean Peninsula*. Journal of Applied Science, 11, 2441, pp. 1–15.

Coşkunsu, G. et al. (2020). Ancient Mirrors: Always Reflective and Generally Secretive Objects of The Past Cultures. XIX$^{th}$ World UISPP Meknès.

De Chavez, P. (2010). *Historic Mercury Amalgam Mirrors: History, Safety and Preservation*. Tech Notes, Williamstown Art Conservation Center, pp. 23–26.

de Figueiredo, E. (2010). *A Study on Metallurgy and Corrosion of Ancient Copper Based Artefacts from the Portuguese Territory*, PhD thesis, Universidade Nova de Lisboa, Faculdade deCiências e Tecnologia, Lisboa.

De Ryck, I. (2004). *Study of tin corrosion: the influence of alloying elements*. Journal of Cultural Heritage 5, pp. 189–195.

De Young, G. (2008). *Metallurgy in Egypt*. In Encyclopedia of the History of Science, Technology, and Medicine in Non-Western Cultures (eds. Selin, H.).

Derriks, C. (1995). *Un miroir cariatide égyptien en bronze*. In: Les cahiers de Mariemont, volume 26, pp. 51–62.

Dilo, T. Civici, N. Stamati, F. Cakaj, O. (2014). *Archaeometallurgical Characterization of Some Ancient Copper and Bronze Artifacts from Albania*. 7th International Conference of the Balkan Physical Union, (eds.) A. Angelopoulos and T. Fildisis, pp. 985–990.

Elhosary, M. H. (2022). *Part of an unidentified artifact from the faience at the Arab El-Hesn antiquities store in Al-Mataria no. 241*. Journal of the Faculty of Arts-Mansoura University 71th Issue- OUG, pp. 127–141.

Enoch, J. (2006). *History of Mirrors Dating Back 8000 Years. American Academy of Optometry*, Optom Vis Sci., Vol. 83, No. 10, pp. 775–781.

Figueiredo, E. (2010). *A Study on Metallurgy and Corrosion of Ancient Copper Based Artefacts from the Portuguese Territory*, Lisboa.

Harrington, N. (2018). *A world without play? Children in ancient Egyptian art and iconography*. Chapter 19, the Oxford Handbook of the Archaeology of Childhood. (eds. Crawford, D. Hadley, G. Shepherd).

Hawass, Z. (2013). *King Tutankhamun: the treasure of the tomb*. The American University in Cairo Press.

Ingo, G. de Caro, T. Riccucci, C. et al. (2006). *Large scale investigation of chemical composition, structure and corrosion mechanism of bronze archeological artefacts from Mediterranean basin*. Appl. Phys. A 83, pp. 513–520.

James, T. De Luca, A. (2000). *Tutankamun*. The American University in Cairo Press.

Koh, Y. (2006). *Laser Cleaning as a Conservation Technique for Corroded Metal Artifacts*. Doctoral Thesis, Luleå University of Technology Department of Applied Physics and Mechanical Engineering Division of Manufacturing Systems Engineering.

Laver, M. (1978). *Spot tests in conservation: metals and alloys*. ICOM-CC, pp. 1–11.

Liang, L. and Parker, Q. (2021). *Close up to the surface: reflections on a preliminary forensic study of four Chinese bronze mirrors*. Heritage Science, pp. 9–25.

Lilyquist, C. (1979). *Ancient Egyptian Mirrors, from the Earliest Times through the Middle Kingdom*. Münchner Ägyptologische Studien 27.

Lowder, S. (2023). *The History of Mirror: Through A Glass, darkly*. [online] Furniture Library, Available at: https://www.furniturelibrary.com/mirror-glass-darkly/ [accessed 3 Jan 2023].

Macleod, I. (1981). *Bronze Disease: An Electrochemical Explanation*. ICCM Bulletin 7(1), pp. 16–26.

Mahran, H. and El-Kilany, E. (2016). *What Lies under the Chair! A Study in Ancient Egyptian Private Tomb Scenes, Part II: Objects*. JARCE 52, pp. 11–33.

Ministry of tourism and Antiquities, *Tanis's Collection: Pharaohs Treasures - Dynasties 21st, 22rd*, Egyptian Museum in Cairo, 2020.

Nicholas, G. (1988). *A History of Ancient Egypt*, Librairie Arthéme Fayard, p. 27.

O'Neill, B. (2011). *An Overview on Egyptian Mirrors from Prehistory to the New Kingdom*. Reflections of Eternity, pp. 1–16.

Odler, M. and Kmošek, J. (2020). *Invisible Connections: An Archaeometallurgical Analysis of the Bronze Age Metalwork from the Egyptian Museum of the University of Leipzig*. Archaeopress Egyptology 31, Charles University, Faculty of Arts.

Odler, M. (2016). *Old Kingdom Copper Tools and Model Tools*, Archaeopress Egyptology 14, Charles University, Faculty of Arts, Czech Institute of Egyptology.

Odler, M. (2021). *Ancient Egyptian Metallurgy*. in History of Applied Science & Technology: An Open Access Textbook, (eds. Skjelver, D. Arnold, D. Broedel, H. Glasco, Sh. and Kim, B.). Grand Forks, ND: The Digital Press @ UND.

Pendergrast, M. (2004). *Mirror: A history of the human love affair with reflection*, The Journal of American Culture; Malden Vol. 27, Iss. 2, pp. 245-246.

Pollard, A. Thomas, R. and Williams, P. (1989). *Synthesis and stabilities of the basic copper (II) chlorides atacamite, paratacamite and botallackite.* Mineralogical Magazine, 53 (373), pp. 557–563.

Rehren, T. (2020). *Metals*. In M. Richards & K. Britton (eds.), Archaeological Science: An Introduction, Cambridge University Press, Cambridge.

Reisner. G. (1910). *Archaeological Survey of Nubia, 1907-08.* Cairo.

Rifai, M. et al. (2023). *Technical and Conservation Study of a Bronze Mirror from Aniba, Lower Nubia, Egypt.* SCIENTIFIC CULTURE, Vol. 9, No 1, (2023), pp. 21–35.

Riss, D. (1993). *Testing for Chlorides with Silver Nitrate*, National Park Service, pp. 1-2.

Scott, D. (1991). *Metallography and Microstructure of Ancient and Historic Metals*, The Getty Conservation Institute.

Scott, D. (2002). *Copper and Bronze in Art: Corrosion, Colorants, Conservation*. The

Getty Conservation Institute: Los Angeles, California, USA.

Scott, D. (2014). *Metallography and Microstructure of Metallic Artifacts*. In book: Roberts B., Thornton C. (eds) Archaeometallurgy in Global Perspective, pp. 67–90.

Scott, D. (2020). *A review of copper chlorides and related salts in bronze corrosion and as painting pigments*. Stud. Conserv. 45, pp. 39–53.

Scott, D. et al. (1991). *Ancient & Historic Metals Conservation and Scientific Research.* Proceedings of a Symposium Organized by the J. Paul Getty Museum and the Getty Conservation Institute.

Smith, E. and Jones, W. (1911). *The Archaeological Survey of Nubia. Report for 1907–[1911].* Cairo: National Print Dept.

Soto, L. Franey, J. Graedel T. and Kammlott, G. (1983). *On the Corrosion Resistance of Certain Ancient Chinese Bronze Artifacts.* Corrosion Science, Vol. 23, No. 3, pp. 241–250.

Stoneman, R. (2016). *Alexander's mirror*, in Alexander the Great and the East: history, art, tradition. (Eds. Krzysztof & Wojciechowska), pp. 239–243.

Thomas, E. (2022). *Shining Light on Egyptian Mirrors: New Scientific Research into Their Metallurgy*, University of Liverpool.

Thomas, R. and Acosta, C. (2017). *Jewellery and mirrors*: Naukratis: Greeks in Egypt. the British Museum, pp. 1–30.

Vanessa. D. (2021). *The Phoebe A. Hearst Expedition to Naga ed-Deir, Cemeteries N 2000 and N 2500.* Harvard Egyptological Studies.

Vit, V. and Rappenglück, M. (2016). *Looking Through a Telescope with an Obsidian Mirror. Could Specialists of Ancient Cultures Have Been Able to View the Night Sky Using Such an Instrument*, Mediterranean Archaeology and Archaeometry, Vol. 16, No 4, pp. 7–15.

Weber, H. (1928). Catalogue *of the Collection of Greek, Roman, and Egyptian Antiquities*. London.

Weichert, M. (2004). Trees, *bunches, cauliflowers – A closer look at sulphurous corrosion on copper alloys and minerals ('Black Spots')*. Proceedings of Metal 2004, National Museum of Australia, pp. 149–159.

Yang, J. (2000). *X-ray Radiography Applied to the Study of the Ancient Manufacturing Technique and the State of Conservation of Cultural Relics*, 15th World Conference on Nondestructive Testing, Roma, Italy.

Yao, Z. et al. (2020). *Analysis of Two Bronze Mirrors with Tin-rich Surface*. Research Square, pp. 1–30.

Yokota, MSugaya, F. Mifune, H. et al. (2003). *Possibility of Bacteria-Induced Corrosion of Ancient Bronze Mirrors Found in Ground*. Materials Transactions, Vol. 44, No. 2, pp. 268–276.