DETERIORATION AND CONSERVATION OF AN ARCHAEOLOGICAL BYZANTINE LEAD SARCOPHAGUS FROM JERASH, JORDAN

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1. Introduction

Lead sarcophagi were used for burial in ancient Jordan [1]. An example of a lead sarcophagus is housed in the Archeological Technicalities Store at the Directorate of Jerash Antiquities Governorate with the museum artifact number (1824). The sarcophagus was found in the southeastern corner of the area (cemetery) in Jerash, in Jordan (Figure 1); its height is about 150 cm from the level of the ground with a depth of approximately 55 cm; it retains all the essential elements, including parts of the side stones which supported the sarcophagus and the lead cover. Both the sarcophagus and its cover are ornamented with raised, relief-type drawings of human forms, statues, and twisted ropes on all sides of the body and the cover. The manufacture of the sarcophagi was usually identical and took place in the nearby area in some local workshops [2]. The lead was poured into the base and the long sides of the sarcophagus together, while the short elements were poured separately.

The lids of the lead sarcophagi discovered in Jordan are either plain or slightly curved [3-4]. Craftsmen carefully welded the edges and corners, that were carefully handled, to seal the lid and the sarcophagus together. This method of welding for the final closure of the ark was done for funerary reasons only. The molds that were used to shape these sarcophagi were often made of leather-hard pottery, or finely polished pottery so that the decorations could be clearly distinguished [5]. The molds used to

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produce some of the decorative ornaments were divided within a frame or an architectural unit; in other cases, it was possible to add the decoration alone. This meant the molds could be used multiple times and moreover, as they were made of wood, they were biodegradable [2].

The reason for the decoration of the sarcophagi can be found in the choice of decorative elements whose meaning or potential symbolism reflects the religious consequences for the dead. Modest lead sarcophagi bear common decorative elements, such as symbols of divinity, showing, for example, a partial [6] or a complete scene of the goddess Rhenionius the goddess of wine used to protect the deceased from human beings and to benefit from their entry into the realm of death [7]. Even simple decorations such as the regular lines placed throughout the various sarcophagi in Jordan were also used to protect the deceased from evil, bearing in mind that the Roman Period was one of idolatry [8]. Lead sarcophagi are considered of very great importance to the history of any archeological site [9]. Based on the funeral drawings, statues, and the twisted ropes that spread across the body and cover of the sarcophagus examined in the present study, the sarcophagus is referred to the Byzantine period. The leaden coffer was exposed to many factors of mechanical damage, as a result of its transferal from the place where it was excavated to its present storage place.

After an initial inspection of the sarcophagus and due to the damage caused by poor transport, storage, and unsuitable conservation conditions, it was found that the sarcophagus was in urgent need of maintenance and restoration [10] (Figure 1). The measurements of the sarcophagus were also recorded as follows: cover – 216 cm length, 95 cm width, 15 cm depth; body – 210 cm length, 61 cm width at the head, and 60 cm width at the feet. Height of the sides: max. height 45 cm, to min. height 44 cm at the head and feet. The aim of this study, therefore, was to examine the deterioration phenomena and subsequently proceed with the treatment, restoration, and preservation of the lead sarcophagus displayed at the Archeological Technicalities Store at the Directorate of Jerash Antiquities Governorate in Jordan.

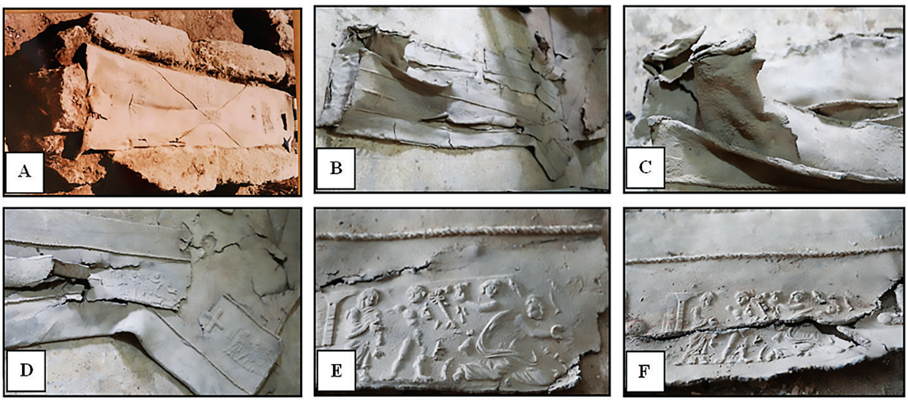

Figure 1. Sarcophagus in the store of the Directorate of the archaeology, province of Jerash. A) The sarcophagus during its discovery in 2003; B) damaged part of the sarcophagus; C) detail of side; D) decorated side; E) detail of decoration on outside; F) decoration on outside: details of cracks, disfigurement of the body and corners of the sarcophagus; repeated decorative unit on the sarcophagus representing an ancient Greek legend.

1.1. *Decorations on the sarcophagus*

The scene depicts Hermes Psychopompos bringing the soul of a man before Hades and Persephone. Hermes is wearing a short mantle fastened on his left shoulder and is holding a caduceus in his left hand; he is accomplishing his duty as Hermes Psychopompos, or conductor of souls in the underworld. The god is turning around and looking at the veiled man representing the deceased owner of the sarcophagus, whom he is leading by the hand [11]. The man is holding an object or perhaps a wrapped paper with his right hand. On the right, Persephone is holding a special type of torch in her right hand, which was used in the Eleusinian mysteries, and a long torch in her left hand. Behind her is Hades, who is looking at her and holding a cornucopia with both hands or left hand. The abduction is often depicted in Greek art with Persephone being taken away on Hades' chariot, sometimes accompanied by the messenger god, Hermes [12].

2. Materials and Methods

Optical microscopy (OM) and stereomicroscopy (SM) were used to provide a wide range of data relating to the patina features and surface characteristics of the lead sarcophagus. Scanning electron microscopy equipped with energy-dispersive X-ray microanalysis (SEM-EDX) was used for investigation and elemental analysis of the deterioration phenomena. SEM micrographs and EDX spectra of the selected samples were obtained by using a JSM-6380 LA instrument, equipped with a Link EDX operating up to 30 kV. An X-ray diffractometer (XRD) was used to identify the corrosion compounds to obtain complete information about the corrosive medium, using a Philips X-ray Diffractometer type: PW1840, tube anode: Cu, start angle (2 θ º): 1 º and end angle (2 θº): 60º.

3. Results

3.1. *Optical microscope examination*

The optical microscope examination of the corrosion layer showed the surface of lead metal and the lead corrosion compounds: the irregularity of the surface is due to the storage of the sarcophagus in inappropriate conditions. Many fissures and cracks were also observed, in addition to soil deposits on the surface (Figure 2).

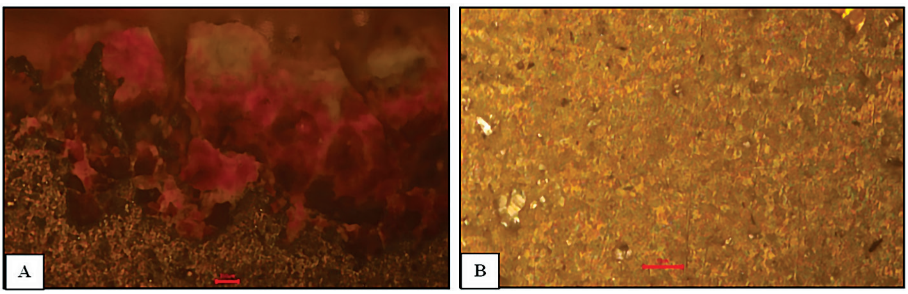

Figure 2. Optical microscope image of the lead sample. A) red corrosion on surface; B) irregularity of surface and presence of soil deposits.

3.2. Stereo microscope examination

The optical microscope examination of the lead samples showed the presence of grains of soil in which the sarcophagus was buried, sticking to the surface; the presence of deep cracks in different directions; the corrosion products have heterogeneously interfered with the lead metal. There are also gaps, cavities, and areas of erosion in different parts of the lead surface (Figure 3A, B, C, D).

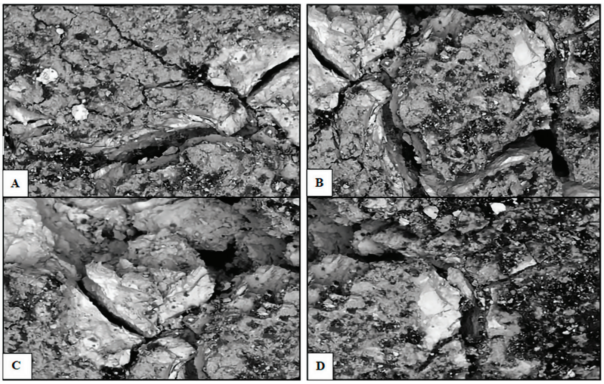

Figure 3. A) Erosion, cracks, and heterogeneous corrosion layers; B) soil grains mixed with corrosion products; C) corrosion layers on the surface of the lead sample; D) deep cracks and corrosion compounds.

3.3. Scanning Electron Microscopy (SEM) examination

Scanning electron microscope investigations illustrated that the unevenness and roughness of the surface is the result of erosion due to its being buried in the soil with components that have caused the formation of corrosion products. The presence of various separations and cracks were also observed. The corrosion compounds appeared as a dark color on the surface, interfering with the lead metal (Figure 4A, B, C, D).

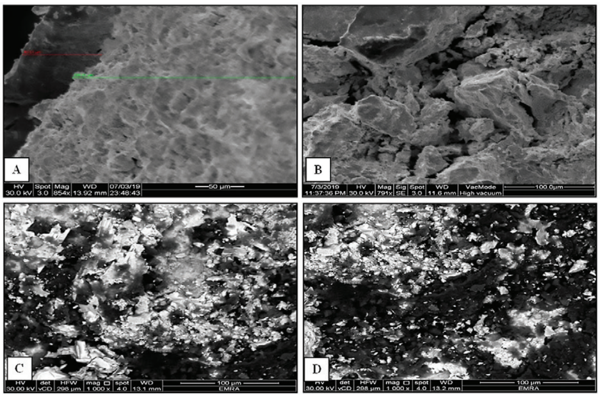

Figure 4. Scanning electron micrograph: A) corrosion layer; B) cracks and disintegration with voids, C) erosion and presence of corrosion products; D) corrosion compounds appear in a dark color on the surface.

3.4. Elemental analysis by EDX Unit

Scanning electron microscopy (SEM) equipped with energy-dispersive spectrometry (EDX) was used to study the lead samples of the sarcophagus. The EDX analysis of the corrosion layer representing the metallic core revealed that it contains Pb as the major element, and small amounts of Si, Ca, O, Al, Mg, K, Na, and Fe, (Figure 5A and B and Tables 1A and B).

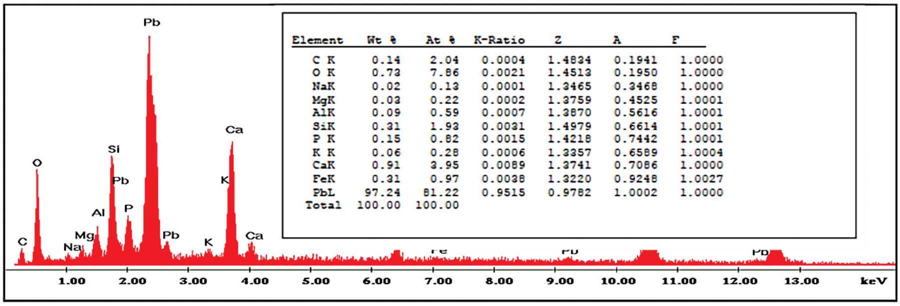

Figure 5. A) EDX pattern of the lead sample.

Table 1A. EDX analysis results of the lead sample.

Element	C	O	Na	Mg	Al	Si	P	K	Ca	Fe	Pb	Total
Percentage %	0.14	0.37	0.02	0.03	0.09	0.31	0.15	0.06	0.91	0.31	97.24	100

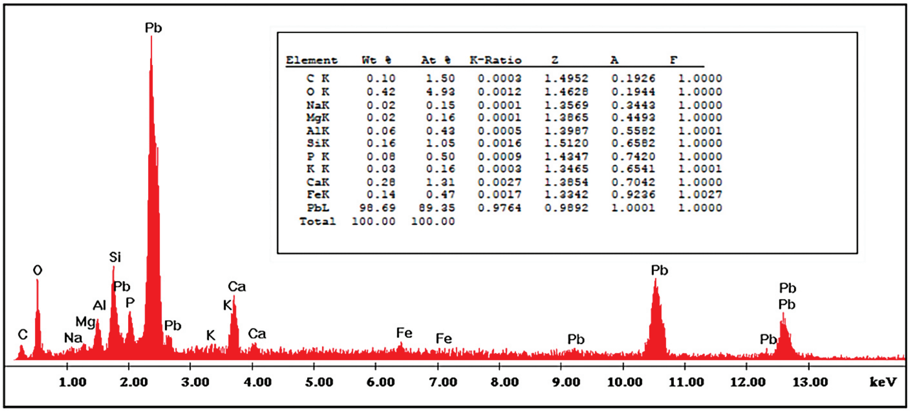

Figure 5. B) EDX pattern of the lead sample.

Table 1B. EDX analysis results of the lead sample.

Element	C	O	Na	Mg	Al	Si	P	K	Ca	Fe	Pb	Total
Percentage %	0.10	0.42	0.02	0.02	0.06	0.16	0.08	0.03	0.28	0.14	98.69	100

3.5. XRF elemental analysis

The XRF analysis of the lead samples revealed that it contains Pb as the major element, in addition to Ca, Fe, and Ir as an impurity, (Figure 6A and B and Table 2).

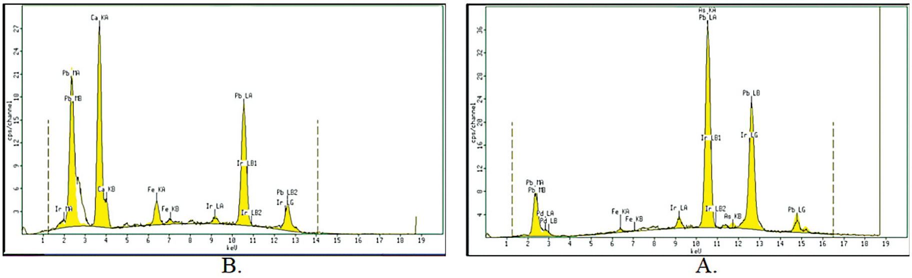

Figure 6. A) XRF pattern of the lead sample; B) XRF pattern of the lead sample.

Table 2. XRF Analysis results of the lead sample.

Element	Percentage %	Oxide	Percentage %
Ca	0.56380	CaO	15.64786
Fe	0.24212	Fe_2O_3	0.81464
Ir	1.09809	IrO_2	0.14801
Pb	97.17810	PbO	83.38949

3.6. X-Ray diffraction analysis

The XRD spectrum of the samples consists of graphite (C), lead (Pb), litharge (PbO), cerussite ($PbCO_{3)}$, hydrocerussite ($2PbCO_3$.Pb $(OH)_2$) (Figure 7A and B and Table 3).

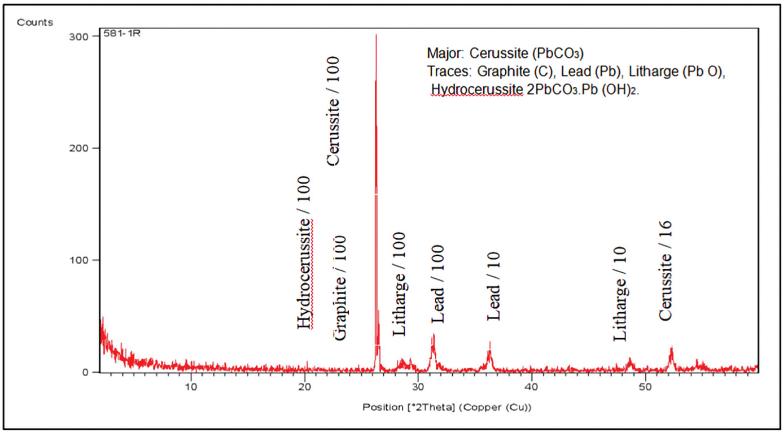

Figure 7. A) XRD pattern of the lead sample.

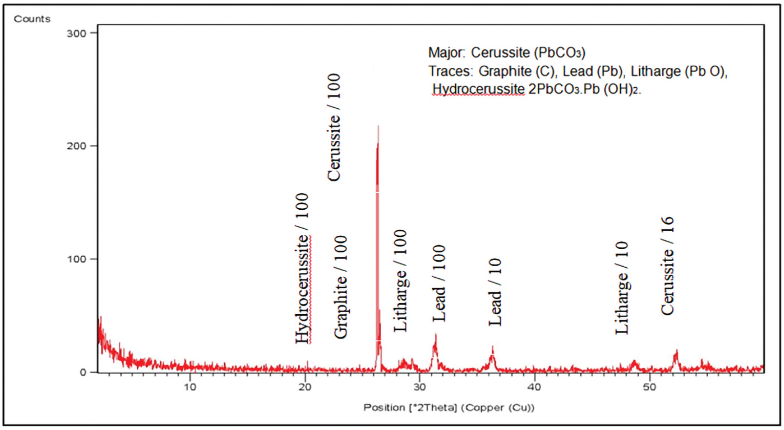

Figure 7. B) XRD pattern of the lead sample.

Table 3. XRF analysis results of the lead sample.

No.	Mineral Name	Chemical Formula
1	Graphite	C
2	Lead	Pb
3	Litharge	PbO
4	Cerussite	$PbCO_3$
5	Hydrocerussite	$2PbCO_3.Pb(OH)_2$

4. Conservation and protection against corrosion

4.1. Adjustment and rectification of the torsion

This process is one of the most challenging treatments, as it took a long time and great effort. During the process, great care was taken of the existing decorations, so as not to deform their appearance, as a possible result of the operation of gentle knocking using silicon hammers. All sides of the sarcophagus (cover and body) underwent the rectification process and adjustment of the torsion, using silicon hammers, so as not to leave traces on the inherently soft lead material. Iron vises were also used with traction on each side of the sarcophagus between two boards of wood; pressure was applied gradually over fifteen days, so as not to cause any sudden stress which could lead to the material (lead) breaking or cracking (Figure 8 A, B and C).

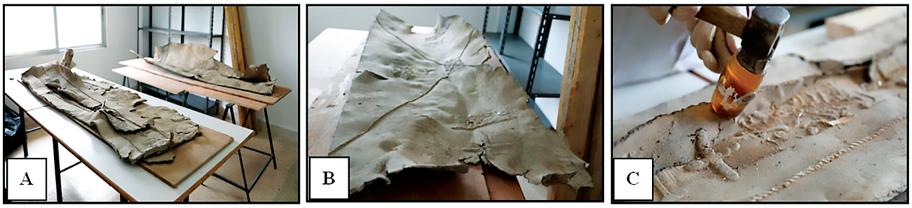

Figure 8. A) The sarcophagus after being moved from the warehouse to the laboratory; B) cover of the sarcophagus during the process of rectification; C) gentle knocking using a hammer with a silicon head, the cross is clearly visible on the cover.

4.2. Cleaning

This stage was aimed at removing the dirt and damaged products that distorted the shape of the sarcophagus and included dust, foreign particles, and rust products, etc. During this process, the dirt was removed by breaking the bond between it and the archeological soiled surface, mechanically and chemically. The cleaning leads to removing all the soil marks, restoring the 'readability' of the decoration of the sarcophagus and its subtle details. The cleaning also involved the removal of deformed external and distorted parts of the sarcophagus surface. The cleaning stage is an initial stage of treatment followed by other multiple steps and must therefore be carried out accurately and with acute awareness, to conserve and repair the damaged signs and features of the sarcophagus.

4.2.1. Mechanical cleaning

Mechanical cleaning is the most controllable method and the safest, if done accurately. It is also easy and safe to use, as it does not produce any chemical products that may cause damage to the archeological object. Mechanical cleaning usually gives highly excellent cleaning results; hence, chemical cleaning may not be required [13]. It is, therefore, preferable to use mechanical cleaning and to resort to chemical cleaning only if strictly necessary. The purpose of mechanical cleaning is to maintain the signs of deterioration without causing any damage or surface scratching of the lead or making any change in the shape and color of the sarcophagus. Mechanical cleaning, moreover, does not require the addition or removal of any material that weakens or damages the lead. Mechanical cleaning includes the removal of surface dust and suspended dirt on the surfaces of calcined sediments, especially from the soil accumulated during the burial process and the products of corrosion [14].

This is done by using various types of brushes, sponges, an air compressor, and a vacuum cleaner with different brush shapes, etc. as well as other various fine tools, such as needles, dispensers, dental tools, spatulas, different sized scalpels; the most appropriate tool is selected and used, according to the quality and strength of the lead to be treated, and on condition that removal of the dirt must be done without directly penetrating the surface of the archeological object. In fact, cleaning of the sarcophagus began with a mechanical process using soft bristles; then, the loosened dirt was removed using a vacuum cleaner, and a range of different sized and textured brushes adopted, according to the state of the existing quantity and degree of hardness of the calcinations, (e.g. using soft, fiberglass brushes) (Figure 9A and 9B).

4.2.2. Chemical cleaning

The use of chemicals for cleaning is minimized to protect the sarcophagus from any damage that may be caused by their use, since chemical cleaning and its soluble products are difficult to control and may cause future damage to the lead; the toxic characteristics of such chemicals, moreover, could affect the restorer who employs them. The chemical cleaning included the removal of calcinations produced by rust products. The sarcophagus was thoroughly cleaned and the rust products, suspended dust, and calcined and strong deposits, were removed using dental instruments, sometimes applying alcohol and turpentine in a ratio of (1 : 1) and to help in the eradication of fungus, and sometimes EDTA (ethylene diamine tetra-acetic acid) in a low concentration (10%) [13] (Figure 9C).

Figure 9. Mechanical cleaning; A) hair detangler brush; B) applicator brush; C) toothbrush for chemical cleaning of the sarcophagus.

4.3. Consolidation

Due to a large number of cracks, gaps, and missing parts on the sarcophagus, a decision was made to strengthen it with an inner box of Plexiglass. The same idea was applied to the lead sarcophagus at the Jordanian Heritage Museum at Yarmouk University, where it proved to be effective even after several years. In the application, the interior of the sarcophagus body is reinforced by using Plexiglass panels as a supporting inner box, with a thickness of (5mm) for each of the four sides. A binder made of Paraloid B72, which can resist high temperatures, was used in a concentration of 20% and the thermoplastic resin transparence of the Paraloid falls within the limits of international restoration charters [9]. The plexiglass panels were scratched with a sharp metal tool, such as nails, to ensure the bonding of the parts. Plexiglass plate was used because it is chemically inert, strong and transparent, and resistant to deterioration factors, such as ultraviolet radiation and polluting agents. The internal box, made of plexiglass is equal in size to the length and width of the sarcophagus so that it helps in the reinforcement and the process of filling the gaps for the missing parts. Iron vises and wooden planks were used to assist in the adhesion process.

4.4. Fixing the broken and missing parts

Because of the presence of many broken and detached elements from the sarcophagus, the process of fixing these parts using Paraloid (B72) glue in a concentration of 20% was carried out as a solution and the pieces properly positioned. Everything was then assembled with the new supporting holder made of plastic glass, used as an inner box for the sarcophagus body (Figure 10 A-F).

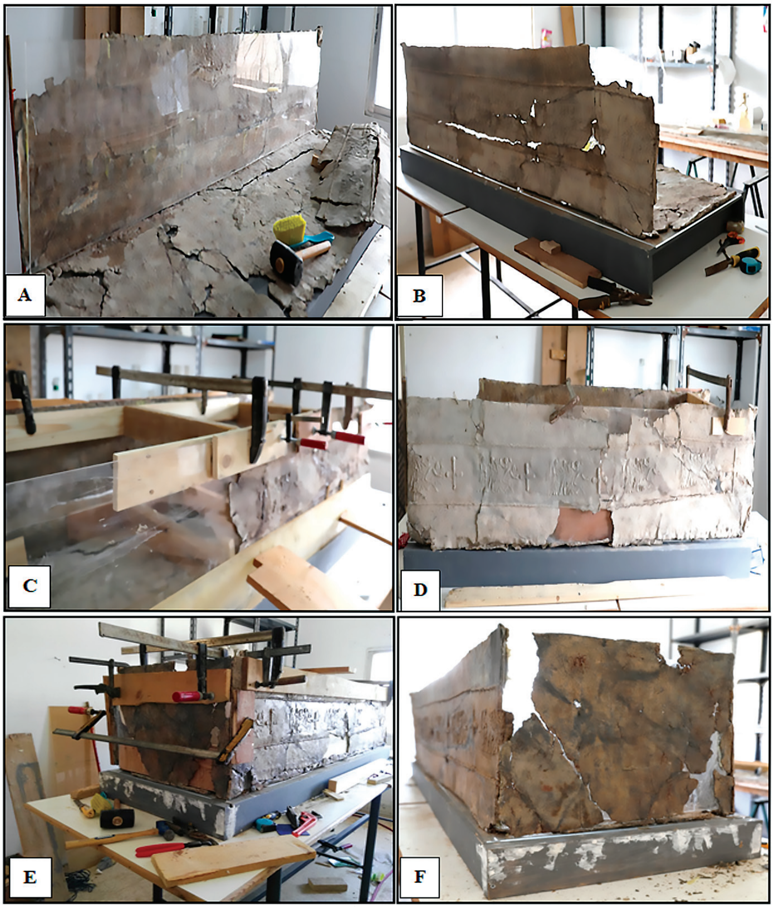

Figure 10. A) Plexiglass panel after it is fixed onto the side of the sarcophagus as a support element (skeleton); B) and C) rectifying the sarcophagus and positioning it in the new holder; D) and E) joining the sarcophagus sides to each other on the plexiglass sheet by means of iron vises and wooden panels; F) fixing the smallest side of the sarcophagus to the plexiglass; the missing parts are visible from inside, thereby fulfilling UNESCO conservation requirements.

4.5. Completing and filling the missing parts

The process for treating the missing parts, the gaps, and cracks was then carried out. This involved using natural substances, such as bees' honey wax and 5% Colophony. The Colophony gum is added to the beeswax to increase its hardness and to control the formation process [15]. Honey wax was selected for this purpose since it is chemically inert and does not react with the lead. Also, it is easy to apply and shape and refine and color. During casting, the wax is reinforced using flax yarn fibers to intensify the color, so as to resemble the original color of the sarcophagus' lead surface using natural oxides and to achieve harmony with the original appearance of the sarcophagus (Figure 11 A-H).

4.5.1. Preparation of the materials

The honey wax was put on a flame source until it melted, then the colophony was added after it had been powdered and mixed with 5% hydrogen peroxide to fit and match the color of the sarcophagus; it was then applied and used to cast and fill in the missing parts in the new Plexiglass element [9]. Wax is used when it is warm, and melts at 68 °C; at this temperature the colophony is mixed with the wax to increase its hardness but is still easy to shape because the addition of the colophony increases the degree of the melting point and needs to be prepared very precisely, usually by an experienced person. After completing the missing parts, the excess wax was removed with gasoline as an organic solvent, as well as the outer surface of the entire sarcophagus.

4.5.2. Completing the missing decorative unit

Due to the loss of a large part of the edges of the sarcophagus cover with decorative elements, a clone of one of the existing decorative items on the cover was made; the cloned unit was then installed in place of the missing part [9]. The process of cloning involved making a negative mold form of Parisian gypsum and then a positive one. Once ready, the wax with the colophony was poured into the mold to form the decoration in the same hue as the wax used in the completion process. It was then installed in place of the missing unit. Parts of the crucifix (Figure 8B and C) and the missing tab with the cover of the sarcophagus were also completed with wax [15] (Figure 11A-I).

Figure 11. A) and B) the side of the sarcophagus before and after completion; C) and D) gaps and cracks in the sarcophagus base before and after completion; E) scratching the plexiglass to increase cohesion with the wax; F) sarcophagus cover while using linen fiber on the plexiglass to increase cohesion with the wax; G) and H) scratching the initial layer of wax in preparation for casting a second layer before and after treatment; I) mold and decorative cloning unit.

4.6. Stabilization and coating

At the end of the restoration and completion processes, reinforcement and insulation coating substances were applied over the entire archeological sarcophagus, so the body of the sarcophagus was isolated from the surrounding environmental conditions and damaging factors. The corrosion on the surface of the sarcophagus was protected with a benzotriazole solution in ethanol with a 5% concentration (for stabilization) [16]; it was then coated with B72 using a 5% concentration [9].

4.7. Museum exhibition

Protecting and preserving the lead sarcophagus was done by controlling the surrounding environmental conditions trying to remove the various factors that could damage the sarcophagus and taking precautions to prevent any negative impact on it, so the sarcophagus was exhibited inside a special glass cabinet in Jerash Museum [9]. The glass cabinet was designed to be higher than the body of the sarcophagus by about 8 cm and carry the weight of the cover as well as preventing it from touching the body. The base was also designed with a shorter length than that of the sarcophagus by about 10 cm and a width of less than 8 cm so that it could be placed under the body for the final display of the sarcophagus. The sarcophagus was exhibited in the middle of the hall of the Museum of the Jerash Archaeology Directorate, after selecting the appropriate place inside the museum building and displayed in the transparent glass cabinet (1 cm thickness) designed to surround the sarcophagus on all sides to isolate it from the external environment and prevent visitors from touching it. A base made of natural stone was placed under the sarcophagus with a height of 15 cm, a length of 250 cm, and a width of 100 cm, so it did not touch the ground, thus preventing moisture from reaching it, and making it easier for visitors to the museum to view it on all sides (Figure 12A, B, C). A wooden box-shaped base was also designed, painted and insulated to carry the sarcophagus (Figure 13B); it was then placed inside the glass case.

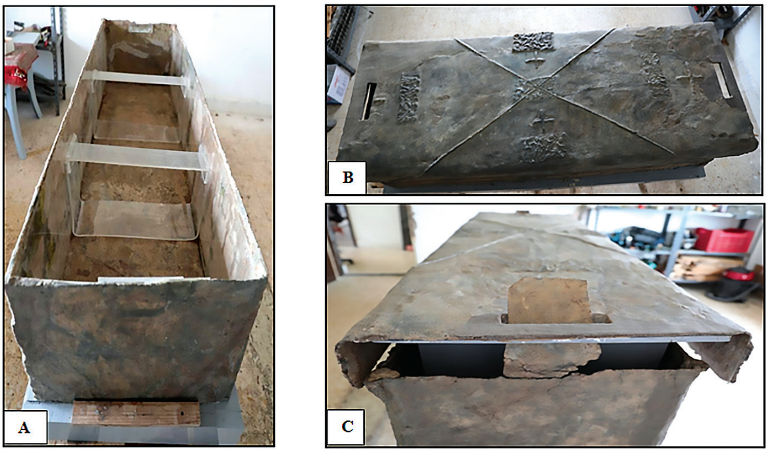

Figure 12. A) plexiglass supports for the sarcophagus sides; B) decorative cloning unit after installing it on the sarcophagus cover; C) closing tongue of sarcophagus on one of the short sides.

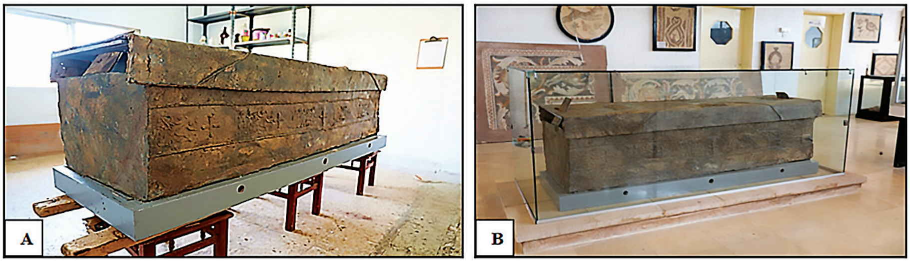

Figure 13 A) Final appearance of the sarcophagus before transferring it to be exhibited in the museum; B) final appearance of the sarcophagus on the stone base while on display in the hall of the Jerash Archaeological Museum.

4.8. Exhibition and storage conditions

Museum officials were instructed to monitor and preserve the appropriate museum environment to exhibit the sarcophagus in, where it is preferable to maintain a level of relative humidity of 25-30% and a temperature in the range of 20-22 °C to reduce the effects that cause metals to deteriorate and to discourage the growth of living organisms. The lighting must not be more than 200 lux to be suitable for metals, especially lead (Figure 13 A and B).

5. Discussion

The causes of lead corrosion are now largely known. During the last decades, great efforts have been made to develop suitable methods and procedures for the stabilization of lead objects. These aim on the one hand to eliminate corrosive agents from the environment of the lead object and, on the other hand, to stabilize objects already affected by active corrosion factors with suitable conservative methods [6]. Lead metal was used in many applications in ancient times because of its high density and ease of casting due to its low melting point [17]. To correctly apply the principles of Corrosion Science to the conservation of metal heritage objects, each specific metal or alloy, construction technique, and particular corrosion problem encountered in a museum, outdoors, or in an archaeological setting should be carefully considered [14]. Corrosion processes vary depending on the metal or alloy, and this consequently affects the protective actions needed for the materials [16]. After the initial inspection of this sarcophagus and due to the damage caused by inappropriate transport, storage, and unsuitable conservation conditions, the sarcophagus was in urgent need of maintenance and restoration, where it was found without any previous restoration.

Work on the sarcophagus was documented before, during and after treatments. To start with, the damage and conservation state were scientifically identified and recorded; this was then followed by a description of the various stages of the work.

Examinations conducted on lead samples of the sarcophagus by optical microscope, stereo microscope, and scanning electron microscope indicated that there was an irregularity in the surface due to the burial conditions of the coffin in the soil, and the loads and stresses it had been subjected to in the soil before it was found, discovered and transferred to the Jerash Museum storage space. Examinations also revealed the presence of a network of fine deep cracks. Layers of corrosion appear in different colors on the surface and inside the cracks and twist haphazardly with the lead metal in the sarcophagus. In addition, the presence of corrosion products on the surface of the lead metal interact with the dust and soil particles attached to the surface of the lead metal.

The analyses conducted to identify the composition of the sarcophagus using the EDX unit attached to the scanning electron microscope and X-ray fluorescence, showed the presence of lead was found in a ratio between 97% and 98%. In addition, small proportions of oxygen, calcium, iron, carbon, silicon, and aluminum were found in the samples. Iridium, one of the rare earth elements, was also shown in the analysis by X-ray fluorescence in a very small percentage. This is considered an indication of the presence of some impurities mixed with the lead metal used for the sarcophagus [15]. It also shows the presence of some minerals from the burial soil components mixed with the metal lead [18]. The analysis by X-ray diffraction to identify the compounds in the sarcophagus revealed the presence of graphite (C), lead (Pb), litharge (PbO), cerussite $PbCO_3$ and hydrocerussite $2PbCO_3.Pb(OH)_2$. The findings indicate that the sarcophagus was formed from lead metal that contained some impurities from other metals. On the other hand, some minerals appeared to represent corrosion products of lead metal as well as being the result of interaction with the metal components in the burial soil; furthermore, the presence of excess salts in the soil poses major problems of corrosion [19]. The presence of a dense layer of lead carbonate ($PbCO_3$) as one of the products of the rust of heterogeneous lead, accompanied by an increase in volume [18], was confirmed after the analysis of a sample of the sarcophagus using X-Ray fluorescence (XRF). On most parts of the sarcophagus unstable lead oxide (PbO) layers can be seen; and many cracks, fractures, and spills are scattered in many places on the body of the sarcophagus.

The loss of some parts of the sarcophagus was a major problem, as well as the destruction and deformation of the sides of the sarcophagus. There was a thin protective layer of lead oxide (PbO), a patina over the metal in the atmosphere [20]. Sometimes the patina layer contains a darker coloured lead sulfate. Another thin white layer was found on the surface of the sarcophagus. Lead artifacts from land sites are often coated with cerussite $PbCO_3$ or hydrocerussite $2PbCO_3.Pb(OH)_2$ [13]. Depending on the burial site and environmental factors, the amounts of lead oxides (PbO and PbO_2) vary [19-20]. Lead is generally corrosion resistant. Despite a commonly low electrochemical potential (-0.12 V), the patina layer will form a stable, adherent layer, and protect the metal from corrosion if the environment is not polluted or unsuitable.

A white corrosion layer of hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) occurs in alkaline soils containing dissolved carbonates. In alkaline soils where carbonates are sparse, lead corrodes into brown, reddened oxides with few carbonates, if any, and traces of lead metal may remain in the cracked corrosion crust [17]. Lead can react with the chloride and sulfur impurities, and oxygen and moisture, which affect the composition of the corrosion layer of the archaeological artifacts [19]. A weak corrosion layer of lead can be destroyed by handling. Moreover, a dry environment after excavation may lead to decay, collapse, and deformation of the lead archaeological artifacts [21]. Lead is generally sensitive to the presence of organic acids, mainly acetic acid (CH_3COOH), formic acid (HCOOH), and formaldehyde (CH_2O). Lead's sensitivity to acid is such that it has often been used as a passive indicator of the concentration of the pollutant in a specific area [22]. These organic acids or their starting materials can be released into the environment by a variety of materials, such as wood and wood products, paints, adhesives, or textiles.

The result of an accelerated corrosion test illustrates the corrosive effect of various materials on lead [21]. The pollutants most frequently mentioned in connection with active lead corrosion in museums are formaldehyde (methanol), formic acid, and acetic acid. When lead is attacked by these acids, it causes the formation of salts, which are then transformed into basic lead carbonates [18]. If these conditions prevail in a specific deposition, lead is unlikely to have the ability to survive for more than half a century of burial. In contrast, lead is resistant to corrosion by seawater and cretaceous soil. The corrosion crust often retains the topographical details of the original surface. However, this crust sometimes deforms, and the remaining details are only found in the center of the underlying metal where it is able to withstand conditions for a longer period. The corrosion penetrates the level of the original surface inside the deformed lead sheets and the corrosion particles can go deeply into the pores and cracks; the lead parts of the body therefore seem more fragile than they appear [23]. Treatment, conservation, and restoration of the sarcophagus were performed by adjusting the torsion, which was one of the most challenging treatment operations and took a great deal of time and effort; care was also taken with the existing decoration in order not to distort its appearance during this process [15]. The mechanical cleaning process is the most accurate, and controllable of the results, and the safest method, as it does not require the addition or removal of any materials.

The goal was to remove the dirt and deterioration products that distorted the overall shape of the sarcophagus, namely, dust, foreign objects, and rust products, by breaking the link between them and the surface of the sarcophagus. This was followed by a chemical cleaning process and included removal of the calcification from the rust products that the mechanical cleaning process was unable to remove [23]. The sarcophagus is supported by an inner box made of 5 mm thick plexiglass sheets. Plexiglass was also used to make a skeleton of the sarcophagus to fix the broken parts by setting them with the inner glass holder of plastic glass, using natural materials such as beeswax resin colophony, which was added to the wax to increase rigidity and to control the formation process; this is because, as it is a constant chemical substance which does not react with lead, it is easy to apply, model, refine and color [24]. The wax was also supported during the casting, using fiber from flax yarn to further increase its rigidity and cohesion — the beeswax was colored using natural oxides to achieve harmony with the original sarcophagus color. A decorative unit from one of the edges of the sarcophagus was cloned to replace another that was lost and then installed in its original place by creating a mold of wax with the same degree of color as the sarcophagus [15]. To conserve and protect the sarcophagus, benzotriazole ($C_6H_5N_3$) with a concentration of 5% was used, and then Paraloid (B72) with a (5%) concentration was used as a final protective coating [25]. Moreover, after completion of the maintenance and restoration, all actions were documented, and the final transfer procedures were recorded by photographing and drawing them, all carried out at Jerash Archeology Museum. The sarcophagus was displayed in a special glass cabinet to protect it from adverse environmental factors. The museum staff was instructed to regulate and maintain a relative humidity of 25-30 %, as well as a temperature of 18-22 C^o, to reduce air moisture content, which causes the destruction of metals and helps the growth of living organisms, and monitor the lighting, which must not exceed 200 lux to be suitable for metals, especially lead.

6. Conclusion

The lead sarcophagus was used for burial in the Byzantine era. It was damaged by the impact of being buried in the soil and the pressure it was exposed to inside the soil layers. After its discovery at the excavation site, the sarcophagus was improperly stored in the Jerash Museum warehouse, which caused further damage. It was then transported to the restoration laboratory, and examinations and analyses were conducted which showed the presence of various deterioration factors, for example, the presence of cracks, surface erosion, distortion and morphological deformation, in addition to the formation of layers of corrosion mixed with grains of the burial soil. The heterogeneous corrosion layers included C, Pb, $PbCO_3$, PbO, and $2PbCO_3.Pb(OH)_2$. Treatment, restoration, and conservation processes for the sarcophagus were carried out. They included mechanical and chemical cleaning, in addition to consolidation, fixing the broken and detached parts, completing and filling the missing parts, reproducing a missing decorative unit, stabilization, and coating. The stabilization of the sarcophagus was accomplished by brushing it with a 3% benzotriazole solution, which formed a thin film on the surface of the artifact to seal the chloride ions with moisture and oxygen. Finally, to protect the artifact from atmospheric humidity and corrosive ions, it was coated with a 5% solution of Paraloid B-72. Finally, conditions for its display in the museum exhibition and storage conditions were adjusted to maintain a healthy environment for its continued preservation.

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References

[1] Bourke, S. J. (2007). The late Neolithic/early Chalcolithic transition at Teleilat Ghassul: context, chronology and culture. Paleorient, 15-32.
[2] Keesling, K. (2008). The Votive Statues of the Athenian Acropolis: Cambridge University Press.
[3] Al Sekheneh, W., Doménech-Carbó, A., Alawneh, F., Al Shiyab, A., & Al Saad, Z. (2017). Authentication of roman corroded lead artefacts from archaeological sites in calcareous environment in jordan by electrochemical analysis. *Mediterranean Archaeology & Archaeometry*, *17*(3).
[4] Keersmaecker, M., et al. (2018) A Short Historical Overview on the Use of Lead in: Chemical Interactions between Cultural Artifacts and Indoor Environment (Eds) Mieke Adriaens, Susie Bioletti and Ira Rabin. Uitgeverij Acco, Blijde Inkomststraat 22, 3000 Leuven, Belgium.
[5] Grossman, J. B. (2014) Funerary Sculpture: American School of Classical Studies at Athens.
[6] Al-Muheisen, Z. & Ajlouni, A. (2005). A Nabataean inscription from Northern Jordan Survey (Umm al-Jimāl area). Syria, pp. 167-171.
[7] Toynbee, J. M. (1996). Death and burial in the Roman world: JHU Press.
[8] Wolff, S. R. (2002) Mortuary practices in the Persian period of the Levant. Near Eastern Archaeology, 65(2), pp. 131-137.
[9] Keersmaecker, M., et al, (2018) How to Preserve Lead Artefacts for Future Generations, Chemical Interactions between Cultural Artefacts and Indoor Environment, (Eds): Mieke Adriaens, Susie Bioletti and Ira Rabin, Uitgeverij Acco, Blijde Inkomststraat 22, 3000 Leuven, Belgium.

[10] Brusic, V., Dimilia, D. D., & MacInnes, R. (1991) Corrosion of lead, tin, and their alloys. Corrosion, 47(7), pp. 509-518.
[11] Smith, E. (1992), Judahite burial practices and beliefs about the dead (Vol. 7): A&C Black.
[12] Pitsios, T., & Zafiri, V. (2012). Cases of Trephination in Ancient Greek Skulls. International Journal of Caring Sciences, 5(3), 239-245.
[13] Palomar, T., et al., (2018), Comparative assessment of mechanical, chemical and electrochemical procedures for conservation of historical lead, Emilio Canoa, Journal of Cultural Heritage, Vol. 30, March, Pp. 34-44.
[14] Letardi, P. (2021), Testing New Coatings for Outdoor Bronze Monuments: A Methodological Overview, Coatings, 11, (2), 131.
[15] Davis, M., Hunter, F., & Livingstone, A. (1995). The corrosion, conservation and analysis of a lead and cannel coal necklace from the Early Bronze Age. Studies in conservation, 40(4), 257-264.
[16] Artesani, A., (2020) Recent Advances in Protective Coatings for Cultural Heritage–An Overview, Coatings, 10, 217.
[17] Elbeshary A., et al, (2018), The Use of a Saturated Long Carbon Chain Sodium Monocarboxylate for the Corrosion Inhibition of Lead Objects in Atmospheric Conditions and in Acetic Acid Corrosive Solutions, Coatings, 8, 118.
[18] Vantelon, D., Lanzirotti, A., Scheinost, A. C., & Kretzschmar, R. (2005). Spatial distribution and speciation of lead around corroding bullets in a shooting range soil studied by micro-X-ray fluorescence and absorption spectroscopy. Environmental science & technology, 39(13), 4808-4815.
[19] Graedel, T. (1994), Chemical mechanisms for the atmospheric corrosion of lead. Journal of the Electrochemical Society, 141(4), 922-927.
[20] Al Sekheneh, W., et al, (2017), Authentication of Roman Corroded Lead Artefacts from Archaeological Sites in Calcareous Environment in Jordan by Electrochemical Analysis, Mediterranean Archaeology and Archaeometry, Vol. 17, No 3, pp. 261-272.
[21] Heath, D., & Martin, G. (1988), The corrosion of lead and lead/tin alloys occurring on Japanese lacquer objects. Studies in conservation, 33, (sup1), 137-141.
[22] Coles, E., Gibson, J., & Hinde, R. (1958). The corrosion of lead by dilute aqueous organic acids. Journal of Applied Chemistry, 8(5), 341-348.
[23] Tylecote, R. F. (1983), The behaviour of lead as a corrosion resistant medium undersea and in soils. Journal of archaeological science, 10(4), 397-409.
[24] Naylor, A. (2000). Conservation of the eighteenth-century lead statue of George II and the role of laser cleaning. Journal of Cultural Heritage, 1, S145-S149.
[25] Van Ham-Meert, A., (2019), Novel analytical protocols for elemental and isotopic analysis of lead coins–Sasanian lead coins as a case study, Archaeological and Anthropological Sciences, 11:3375-3388.

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Summary

The research looks at a Byzantine sarcophagus made of lead, found in Jerash (Gerasa), Jordan, kept in the warehouse of the Jerash Museum under No.1824. The sarcophagus was exposed to unsuitable storage conditions that caused severe damage. Examination by optical stereomicroscope and scanning electron microscope revealed that the sarcophagus suffered from various deterioration phenomena, for example, the presence of corrosion layers, folds and various cracks. The analysis of the sarcophagus by the EDX unit attached to a scanning electron microscope and x-ray fluorescence, showed that it contained 98% lead, in addition to a very small percentage of other elements such as iron, aluminum, sodium, silicon, and carbon. Analysis by X-ray diffraction revealed that the sarcophagus also contained minerals, which included Graphite (C), Lead (Pb), Litharge (PbO), Cerussite $PbCO_3$, Hydrocerussite $2PbCO_3.Pb(OH)_2$. The treatment, restoration, and maintenance stages of the lead sar-

cophagus were then carried out and were followed by mechanical and chemical cleaning and straightening of the deformed areas. The missing parts were also integrated, and the four sides of the sarcophagus were assembled using plexiglass as a support material. Treatment with a benzotriazole solution in ethanol with a concentration of 5%, and with Paraloid B72, also with a concentration of 5% were carried out (coating). The sarcophagus cover was also completely repaired. After completion of the treatment, restoration, and conservation processes of the sarcophagus, a transparent glass cabinet of 1 cm thick was designed for its display inside the Jerash Museum in an environment with a relative humidity of 25-30% and temperature of 20-22 °C.

Riassunto

La ricerca prende in esame un sarcofago bizantino in piombo, rinvenuto a Jerash (Gerasa), in Giordania, conservato nel magazzino del Museo di Jerash con il n. 1824. Il sarcofago è stato esposto a condizioni di conservazione non idonee che hanno causato gravi danni. L'esame allo stereomicroscopio ottico e al microscopio elettronico a scansione ha rivelato che il sarcofago soffriva di vari fenomeni di deterioramento, ad esempio erano presenti strati di corrosione, pieghe e crepe varie. L'analisi del sarcofago da parte dell'unità EDX collegata a un microscopio elettronico a scansione e fluorescenza a raggi X, ha mostrato che conteneva il 98% di piombo, oltre a una piccolissima percentuale di altri elementi come ferro, alluminio, sodio, silicio e carbonio. L'analisi mediante diffrazione di raggi X ha rivelato che il sarcofago conteneva anche minerali, che includevano grafite (C), piombo (Pb), litargio (PbO), cerussite $PbCO_3$, idrocerussite $2PbCO_3.Pb(OH)_2$. Sono state quindi eseguite le fasi di restauro e manutenzione del sarcofago in piombo, seguite da pulitura meccanica e chimica e raddrizzatura delle zone deformate. Sono state integrate anche le parti mancanti e i quattro lati del sarcofago sono stati assemblati utilizzando il plexiglass come materiale di supporto. Sono stati effettuati trattamenti con una soluzione di benzotriazolo in etanolo alla concentrazione del 5%, e con Paraloid B72, anch'esso alla concentrazione del 5% (coating). Anche la copertura del sarcofago è stata completamente restaurata. Al termine degli interventi di restauro e conservazione del sarcofago, è stata progettata una teca in vetro trasparente dello spessore di 1 cm per la sua esposizione, all'interno del Museo di Jerash, in un ambiente con umidità relativa del 25-30% e temperatura di 20-22 °C.