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AN ANALYTICAL STUDY OF A LATE PERIOD MULTI-PIECE CARTONNAGE FROM THE EGYPTIAN MUSEUM IN CAIRO

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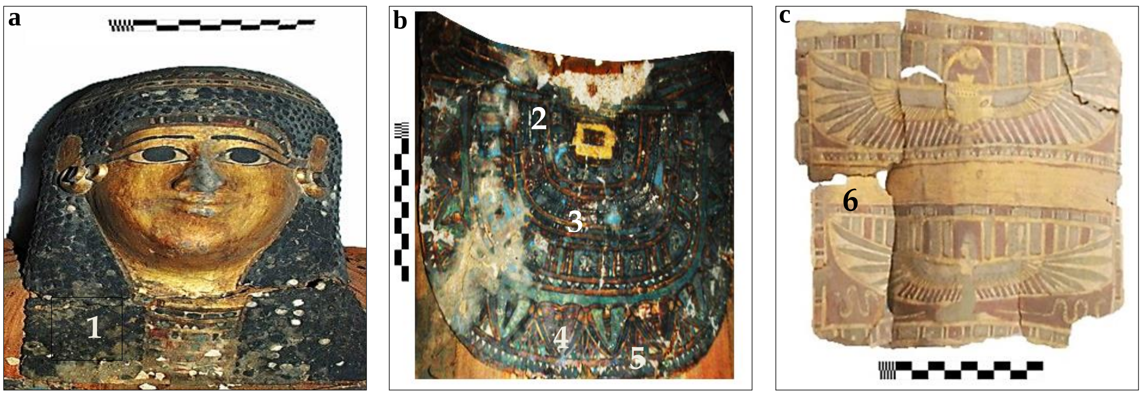
Abstract:
The poor conditions of storage in the basement of the Egyptian Museum were the reason for severe damage to an unknown multi-piece mummy cartonnage dating back to the Late Period (780 BC-332 BC). This mummy consists of five separated pieces (a mask, a pectoral, an apron, a stomach, and a foot) on canvas support topped by a ground layer decorated with green, yellow, red, black, and white colors and a gilded layer. All the pieces of the mummy cartonnage have damage in the form of separations, cracks, discoloration, tears, and brittleness in the layers of the canvas support. The research paper presents the result of an examination and analytical study for the layers' structure of the mummy cartonnage. Therefore, the Optical Microscope (LOM), visible light, Scanning Electronic Microscope (SEM), EDX, Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Diffraction (XRD), and XRF Spectroscopy were used. The results showed that canvas support made of linen in the form of four layers of thin fiber was used in the mask, stomach, and apron pieces. In contrast, one layer of thick fiber canvas was used in other pieces (mask, foot, and pectoral). The ground layer consisted of calcium carbonate, traces of gypsum, and quartz. The painted layer included Egyptian green, malachite, hematite, goethite, goethite with orpiment, graphite, and under layer of Egyptian blue below the green, red, and yellow pigments in a unique technique, especially in the pectoral and foot pieces. It was also noted that animal glue was used in all pigments and colors as a binding medium.

1. Introduction

The ancient Egyptian belief about the afterlife was the reason for the mummification of dead bodies. It was also the main reason for the appearance of cartonnage as an alternative to the features of the deceased to help the spirit reach back the body if the mummy was damaged [1,2]. A cartonnage was put on the mummies and decorated with colors, scenes, texts, and ancient Egyptian writings, which could reveal many facts and historical information [3]. A cartonnage is a type of cardboard-like material. It was used by the ancient Egyptians like our use of papier-mâché. A composite from layers of linen or papyrus was soaked in an adhesive to be flexible enough to accommodate the regular and irregular surfaces, coated with a gesso layer, then decorated with pigments [4,5]. During manufacturing, these layers were molded into a particular shape, then the ground layer of gesso was smoothed before painting and gilding [6,7]. Sometimes, the cartonnage was gilded with pure gold leaf beaten out to form a leaf or as a powder mixed with an organic binder [8]. The cartonnage was introduced in the Middle Kingdom (2025-1700 BC). At the time, the ancient Egyptians began to make the mask in the shape of the deceased's head with facial features, including the borrowed chin. This type of cartonnage was made smaller than the real face. The royal masks were made of hammered gold and studded with precious stones and colored glass [9]. The cartonnage masks continued during the New Kingdom "1085-1567 BC", covered the face completely, and extended to the chest. By the end of the period, the cartonnage covered the entire body. It was molded to the shape of the body, forming a one-piece shell with high decorations, including geometric designs- an assortment of deities and inscriptions of verses from the Book of the Dead [10,11]. In the Greco-Roman Period 780-332 BC, a new simpler method of mummy decoration was used. The mummy was covered with four to six pieces of decorated cartonnage placed on the upper surface of the mummy wrapping. Instead of encasing the mummy, these separate pieces of cartonnage consisted of a mask covering the head and shoulders, a pectoral, an apron for the legs, and a foot casing. Sometimes, two additional pieces were added to cover the ribcage and stomach [3]. In the Ptolemaic and Roman Eras, the cartonnage technique became a mixture of Hellenistic and Egyptian arts due to the faith of the Greeks and Romans in Egyptian beliefs [12]. The pieces of the decorated cartonnage under study are five separate ones taken from an unknown mummy from the Late Period dated back to 688-332 BC from the collections of the Egyptian Museum, Cairo, Egypt (*Accession TR: 1.4.5.15*). The thickness of the painting layer is 0.5-1 mm, containing dif-ferent colors (green, red, yellow, subsurface blue, white, and black, as well as a gilding layer). The canvas support has four layers of fine linen in the apron and rib cage pieces covered with a little thick ground layer. The mask, foot, and pectoral support are made of one thick layer of linen covered by a thick preparation gesso layer decorated with painted and gilded gesso. Investigations were done and proved that this cartonnage is similar in style to other examples dated to the Late Greco-Roman Period, fig. (1). It was found that preserving the cartonnage in the basement of the Egyptian Museum was so poor. The canvas support became darker, more brittle, and separated in some areas. Linen had areas of loss, damage, and discoloration. The green and red pigments became very dark. There were stains, losses, and micro cracks in the painting layer. Furthermore, the gesso layer lost its structural cohesion. The missing parts were caused by many deterioration factors, such as high humidity, temperature, and bad storage. The present study mainly aims to identify the layer structure and characterize painting and gilding materials used to decorate the cartonnage by analytical techniques, such as the Light Optical Microscopy (LOM), Scanning Electron Microscopy (SEM-EDX), X-ray Diffraction (XRD), X-ray Fluorescence (XRF), and Fourier Transform Infrared spectroscopy (FTIR).



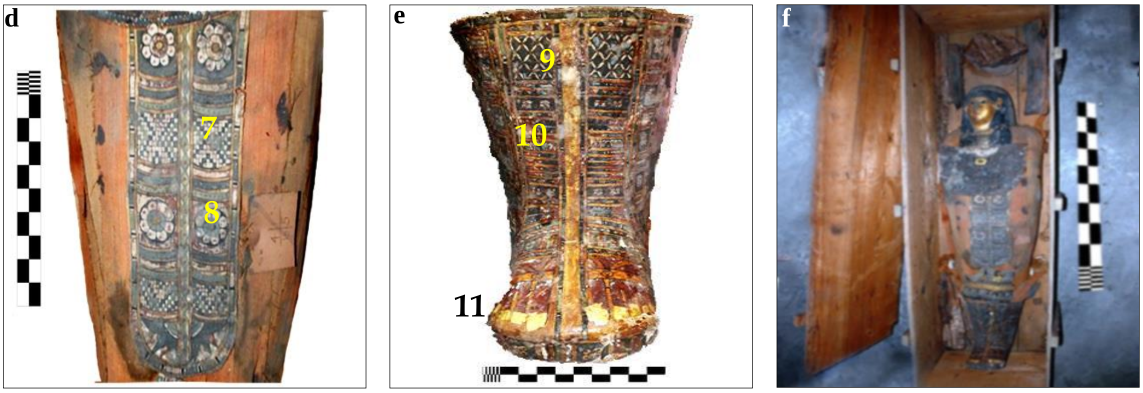


Figure (1) Shows **a.** the mask piece, **b.** the pectoral piece, **c.** the rib cage piece, **d.** the apron piece, **e.** the foot piece, **f.** the total five pieces of the mummy inside the recent wooden box.

2. MATERIALS AND METHODS

2.1. *Samples*

Samples from separated and falling canvas fiber, Gesso layer, red, yellow, green, black, subsurface blue pigment, gilding layer, and binder media were examined and analyzed to identify the structure of the cartonnage layers and to define the nature and degree of damage of the cartonnage layers.

2.2. *USB optical microscopy*

The cartonnage pieces were investigated using a handheld USB digital microscope Dino–Lite with a magnification ranging from 20 to 500-X. This examination helped to study the topography of the canvas layer, the surface stratigraphic structure of the painted layers, and the surface degradation, such as losses and cracks.

2.3. *Scanning electron microscope attached to energy dispersive x-ray analysis (SEM-EDX)*

The samples of the painting layers of green, red, yellow, and black pigments were analyzed using an EDX unit attached with SEM (Model: Quanta 200 FEI) to study the elemental composition. Also, the sample of canvas fibers was investigated to identify the type of textile and evaluate the morphological change. The elemental composition of the ground layer and gilding layer was analyzed using an EDX unit attached to SEM (Model: FEG Quanta 250).

2.4. *X-Ray Diffraction (XRD)*

The samples of the ground layer, red, green, yellow, black, and gilding layer were analyzed to obtain their chemical compositions using Philips X-ray diffractometer (type PW 1710 with Cu tube anode, generator tension 40Kv, generator current 30 MA, Cu k alpha 1 (0.154060) nm, and k alpha 2 (0.154443) nm). The start position was (2 theta 5.0100) and the end position was (2 theta 69, 9900). The software was used for identifying the components "X" pert high score, see tab. (1).

Table (1) XRD results of cartonnage pigments' sample

Color Sample	Minerals	Chemical Formula	Concentration %
Ground Layer	Calcite	$CaCo_3$	68
	Quartz	SiO_2	20
	Gypsum	$CaSO_4.2H_2O$	12
Dark green color	Calcite	$Caco_3$	80
	Quartz	SiO_2	14
	Cuprovaite	$CaCuSi_4O_9$	6
Red color	Calcite	$CaCo_3$	96
	Hematite	Fe_2O_3	4
Yellow color	Calcite.	$CaCo_3$.	93
	Goethite	Fe O(OH)	7
Black color	Calcite	$CaCo_3$	91
	Graphite	C	9
Gilding Layer	Calcite	$CaCo_3$	56
	Quartz	SiO_2	38
	Copper Gold	Cu, Au	6

2.5. *X-ray Fluorescence spectroscopy*

Analyzing the content of the total element was performed using X-ray fluorescence, a portable XRF spectrometer (Elio Spectrometer, XGlab srl, Milan, Italy), designed for using in-situ analyses. The detection of elements from Na to U was carried out, and the field of analysis extended between 1 and 50 keV. X-ray radiation was generated using an Rh tube, with an electron accelerating voltage from 10 to 50 kV and a filament current from 5 uA to 200 uA (Elio Device: SN177; device mode: Head, tube voltage: 40 KV, time measure: 40.0 Sec with manual tube current 20 UA Tube Target is Rh Acquisition, Acquisition, channel: 4096, Sample to Detector Material: by using Air).

2.6. *Fourier-transform infrared spectroscopy (FTIR)*

To characterize the paint media, FTIR spectra were obtained using a Bruker FTIR spectrometer, model VERTEX 70, fitted out with ATR crystal. Using an aperture of 20-100µm, the infrared spectra were acquired in the spectral region 600 to 4000 cm^{-1}. The resolution of 4 cm^{-1} was used with 64 numbers of co-added scans for each spectrum.

3. RESULTS

3.1. *The canvas support*

The investigation results of the light optical microscope on the textile support indicated that the fibers were from linen, which could be characterized by the light optical microscope [13,14]. They also showed the progressive damage in the linen and turning its color to yellowish and dark colors because of the darkness of the binding media [7,15]. The textile fibers degraded and became fragile during burial for a long time due to soiling before being excavated [16]. Textile support consisted of about one to four layers of linen, fig. (2-a, b, c). This result was confirmed by SEM photo micrograph that showed the typical appearance of linen textile, fig. (3-a, b). The micrograph revealed a high degree of degradation and damage. SEM showed that the linen surface was extremely rough, very damaged, and broken.

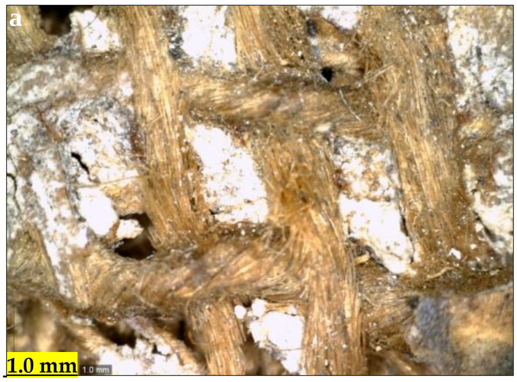


Figure (2) Shows USB microscope proves that the fibers were from linen and shows the degree of deterioration.

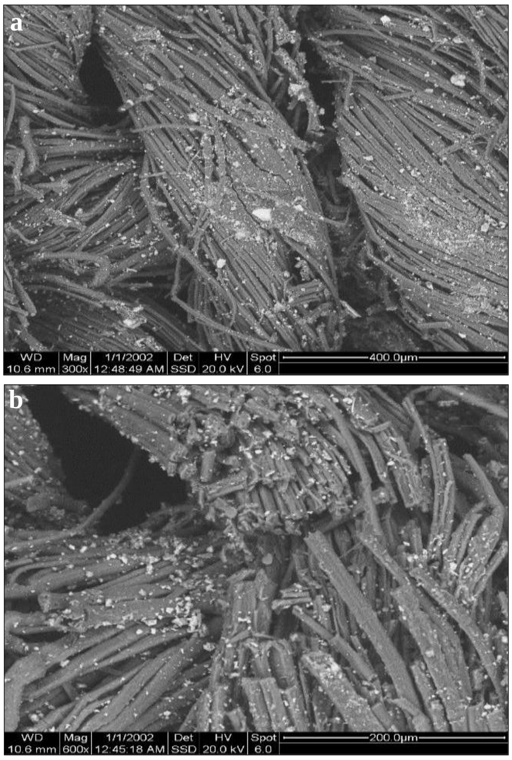


Figure (3) Shows SEM photomicrographs of the damage feature of linen fibers.

3.2. *The ground layer*

The technique of applying the preparation layer in this study was different, as it was applied in the form of two layers. The second layer was smooth, and the first layer that covered the canvas support was coarse, applied in the form of a thick layer in the pectoral and foot pieces figs. (1-b, f & 2). The technique used in the (apron and rib cage) piece applied the white preparation layer directly on the canvas support in one thin layer followed by the painted layer. XRD identified calcium carbonate, gypsum, and quartz, as listed in tab. (1). EDX analysis result revealed the presence of Ca (51.32%), O (40.68%), Si (2.86%), Mg (0.29%), S (1.89%), AL (1.72%), Na (0,11%), P (0.26%), and Cl (0.87%) fig. (4-a) & tab. (2). The analysis indicated that the preparation layer was composed of calcite ($CaCo_3$) as a major component mixed with low percentages of calcium sulfate, gypsum ($CaSo_4.2H_2O$), and quartz (Si) [17]. FTIR on the ground layer, fig. (4-b) showed typical absorption bands of gypsum at 3530, 1620, and 666 cm^{-1}. There was also a band at 1796, 873 cm^{-1} and 711 cm^{-1} due to calcium carbonate [18]. Bands at 1109,779 Cm^{-1} revealed quartz. This result confirmed the results of XRD and EDX.

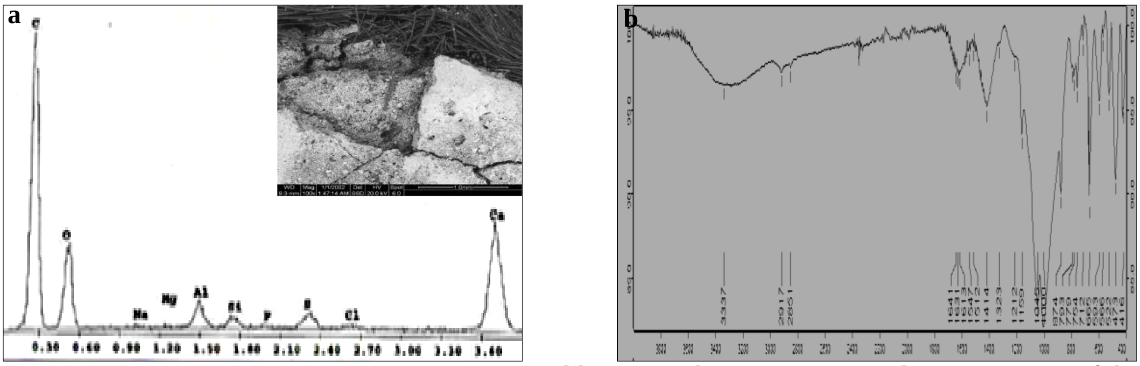


Figure (4) Shows **a.** SEM-EDX pattern of the gro-und layer sample photomicrograph, **b.** FTIR pattern of the ground painting layer.

Table (2) EDAX results of car tonnage pigments

Sample	Elements %												
	O	*Ca*	*Cu*	*Si*	*Fe*	*S*	*Mg*	*AL*	*C*	*Au*	*Na*	*P*	*Cl*
Dark Green	56.27	20.05	7.16	15.47	1.05	-	-	-	-	-	-	-	-
Red	63.23	41.68	-	7.98	6.49	2.48	1.85	3.29	-	-	-	-	-
Yellow	66.1	32.01	-	0.45	0.93	0.28	-	0.23	-	-	-	-	-
Black	47.91	10.15	4.48	10.41	-	0.99	-	1.36	24.7	-	-	-	-
Gold layer	15.52	15.99	-	-	2.50	-	-	-	-	65.93	-	-	-
Ground layer	40.68	51.32	-	2.86	-	1.89	0.29	1.72	-	-	0.11	0.26	0.87

3.1. *Binding media*

FTIR spectroscopic performed to identify the organic medium of pigments and gold samples revealed that the medium was animal glue in all analyzed samples. This result was confirmed by comparing the functional groups that emerged in the samples to characteristic functional groups of animal glue that could appear in FTIR spectrum at (1660-1600) cm^{-1} due to C=O stretching band (amide I) and a band in the region (1565-1550) cm^{-1} due to C–N–H bending band (amid 11), 3400-3200 cm^{-1} associated with the N-H stretching band, 3100-2800 cm^{-1} due to C-H stretching band as mentioned in fig. (5) [19].

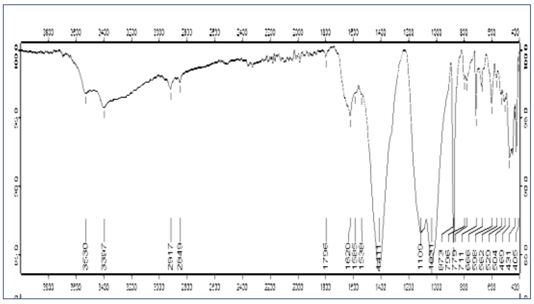


Figure (5) Shows FTIR pattern of the binding media of the pigment sample.

3.2. *The paint layer*

3.4.1. Yellow pigment

The yellow pigment was sampled from a pectoral piece fig. (1-b "4"). It was identified as (yellow ochre) according to an analysis by XRD pattern, tab. (1). Goethite (FeO(OH) and calcite ($CaCo_3$) were recognized as a component of the ground layer. This result was confirmed by EDX data on the yellow sample, which revealed the presence of iron peaks Fe (0.93%), calcium Ca (32.01%), aluminum (0,23%), sulphur (S) (0.29%), oxygen (O) (66.1%), silica (Si) (0.45%)**,** confirming that the yellow color was from yellow ochre (goethite) iron oxide hydroxide+aluminum silicate, fig (6-a). & tab. (2). Ca was the main component of the ground layer. Si, as quartz, and iron (Fe) represented goethite as yellow [20, 21]. The analysis of the yellow pigment was sampled from the foot piece fig. (1-f "10"). XRF, fig. (6-a) & tab.(3) indicated the presence of (Ca, Si, S, Fe, and As). The presence of iron (Fe) was high, but arsenic and sulfur were less. This result confirmed that the color was from yellow ochre (goethite) FeO(OH) mixed with traces of orpiment (AS_2S_3) [22]. LOM investigation of the yellow sample showed the cracks of yellow pigment, fig. (6-c). In contrast, SEM investigation of the yellow sample, and fig. (6-d) showed the damage of the yellow color in the pectoral piece.

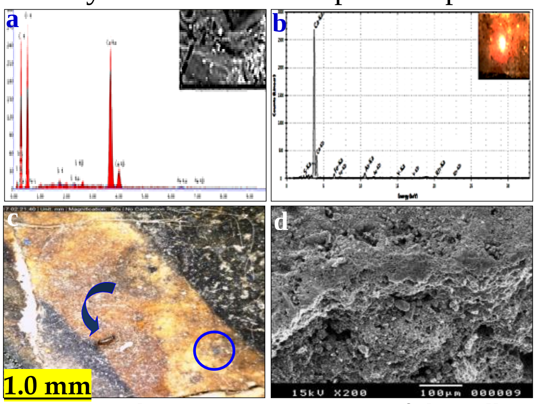


Figure (6) Shows **a.** EDX patterns of the yellow sample, **b.** the results of XRF analysis of the yellow pigment color that appears as Fe, S, **c.** USB photo, **d.** SEM photomicrograph,

Table (3) XRF results of the cartonnage pigments

Elements	Red	Green	Yellow	Blue	Gold	White	Black
	Analytical Results%						
Ca	89.72	88.8	89.62	26.13	65.75	89.72	95.89
As	0.07	0.09	0.38	0.03	-	0.07	-
Fe	3.65	0.43	0.73	0.24	0.75	3.65	3.24
Cu	-	5.71	-	2.04	-	-	-
S	6.55	6.90	9.26	3.88	-	6.55	-
Si	-	-	-	67.55	-	-	-
Cl	-	-	-	-	-	3.21	-
Ti	-	-	-	0.03	-	-	0.86
Au	-	-	-	-	33.44	-	-
Zn	-	-	-	-	0.07	-	-

3.4.2. Red pigment

Red ochre was recognized from the comparison of the elemental analysis by XRF and EDX analysis obtained on the pectoral piece fig. (1-b"5"). EDX showed the presence of hematite ($Fe_2O_3^+$. Iron with alumina silicate minerals (magnesium, aluminum, and silicon) was revealed in the sample that showed the peaks of iron (6.49%), silicon (7.98 %), calcium (14.68%), magnesium (1.85 %), oxygen (O) (63.23%), aluminum (Al) (3.29%), sulfur (S) (2.48%), fig. (7-a) & tab. (2). XRF microanalysis obtained on red pigment showed the presence of Ca, S, Fe, and As, fig (7-b) & tab. (3). The presence of iron (Fe) was high, but the presence of (As and S) was probably due to the presence of yellow orpiment next to red in this area. The presence of calcium (Ca) was due to the preparation layer. XRD analysis identified the red pigment as hematite (Fe_2O_3) and calcite ($CaCo_3$) [3,7], tab. (1). An optical photomicrograph (LOM) obtained on the samples of the red color showed the discoloration and turning of red to black may be due to physiochemical deterioration. The blue color appeared as sub the red color, fig. (7-c). SEM micrograph showed the damage and cracks of the red pigment, fig. (7-d).

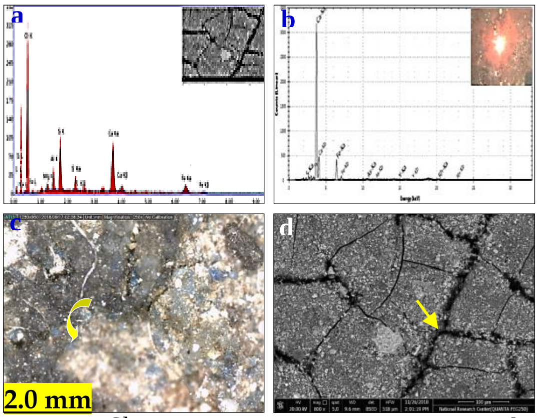


Figure (7) Shows **a.** EDX patterns of the red sample, **b.** the result of XRF analysis of the red pigment of iron (Fe), **c.** USB photo, **d.** SEM photomicrograph

3.4.3. Green pigment

The optical microscope revealed the green pigment with different shades of dark green in the pectoral and foot piece to light green in the apron piece, fig. (1-b "4"). The sample analysis of the pectoral piece, fig. (1-b "4") showed that the green pigment consisted of Egyptian green according to the XRD pattern, tab. (1). The EDX microanalysis, fig. (8-a) & tab. (2) obtained on the green color showed the peaks of silica (Si) (15.47%) in a high percentage, calcium (Ca) (20.05%), copper (Cu) (7.16%), aluminum (Al) (1.05%), oxygen (O) (56.27%). This finding confirmed the results of the XRD analysis that the green color was Egyptian green with a typical chemical formula of Egyptian blue ($CaCuSi_4O_9$). In contrast, the analysis of Pale green by XRF, fig. (8-b) & tab. (3) revealed the presence of iron (Fe) (0.43%). The presence of copper may indicate that the pigment was malachite $CuCO_3.Cu(OH)_2$ or verdigris ($Cu_2CO_3(OH)_2$) or ($Cu_2(OH)_3Cl$) [22,23]. The optical microscope revealed the green pigment with different shades of dark green in the pectoral and foot piece, fig. (8-c) to light green in the apron piece. SEM micrograph showed some damaged features, fig. (8-d).

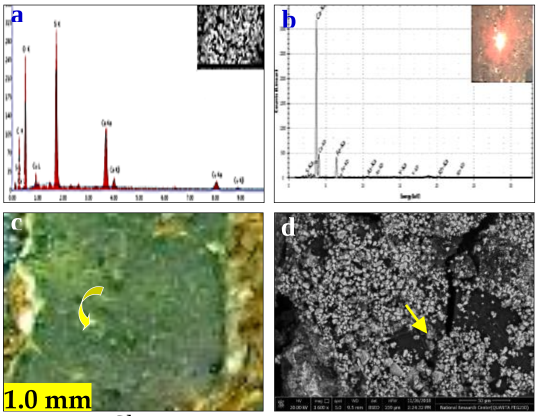


Figure (8) Shows **a.** EDX patterns of the dark green sample, **b.** the result of XRF analysis of light green pigment, confirming the presence of Cu.Ca, As, Fe, **c.** USB photo, **d.** SEM photomicrograph of the shape of cuprovite grains and the crack and damage of the green color,.

3.4.4. Blue pigment.

The light blue pigment was analyzed by XRF, fig. (9) & tab. (3) only in the pectoral piece due to the difficulty in obtaining a sufficient sample for analysis by other methods. It was present as an under layer below the red, yellow, and green colors in both the pectoral and foot pieces. The XRF microanalysis analysis obtained on the under layer of blue pigment revealed that the color consisted of Cu, Ca, Si, and S. Silicon, calcium, and copper correlated with the existence of the cuprorivaite (Ca $CuSi_4O_{10}$), which acted as the primary coloring agent of the synthetic calcium copper tetra silicate compound the main component of the Egyptian blue [24]. The Egyptian blue might be used under the colors to enhance their brilliance [12]. It was reported that light Egyptian blue pigment appeared during the 18th dynasty of the New Kingdom [25].

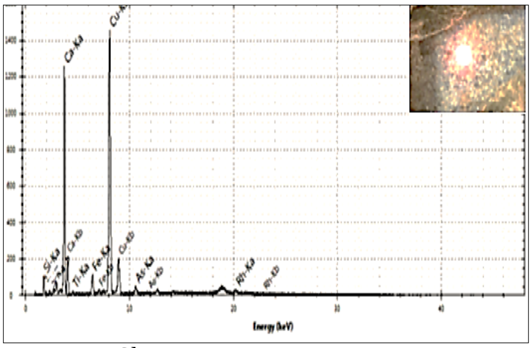


Figure (9) Shows the results of color samples analyzed using XRF; **a.** a subsurface blue layer confirming the presence of copper (Cu), calcite (Ca), and Silica (Si).

3.4.5. White pigment

XRF analysis, tab. (3) & fig. (10) of the white pigment in the apron piece, fig. (1-7 "d"), which was applied around the edges, consisted of gypsum ($CaSO_4 \cdot 2H_2O$). The spectrum indicated the presence of calcium (Ca) (89.72%), sulfur (S) (6.55%), Cl (3.21%), and iron (3.65%), which revealed that the white color was from gypsum, calcium, sulfite-Hydrate ($CaSO_4.2H_2O$) due to the presence of (S), (Fe) as a traces, and

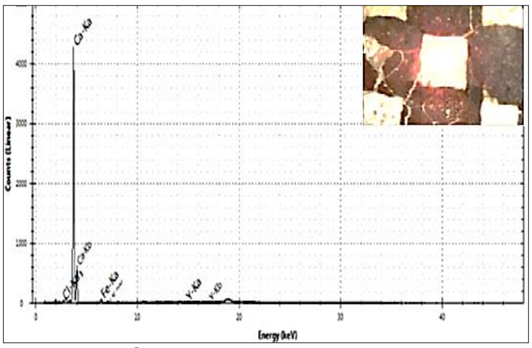


Figure (10) Shows XRF results of white pigment analyzed samples indicating the presence of Ca (calcite), S (sulfur), and F (iron)

3.4.1. Black pigment

The black pigment was sampled from the mask piece, fig. (1-a "1"). XRD analysis indicated that the sample contained black color that was graphite (black carbon), tab. (1). [3,27]. This finding was confirmed by EDX data. It revealed the presence of a high percentage of carbon peaks (C) (24.7 %), calcium (Ca) (10.15 %), silicon (Si) (10.41 %), aluminum (Al) (1.36), oxygen (O) (47.91%), and sulfur (S) (0.99%), fig. & tab (2) (11-a). The investigation of the black pigment by LOM showed the shape of carbon particles in a stable condition, fig_s. (11-b, c) a micrograph by SEM showed the big grains of graphite.

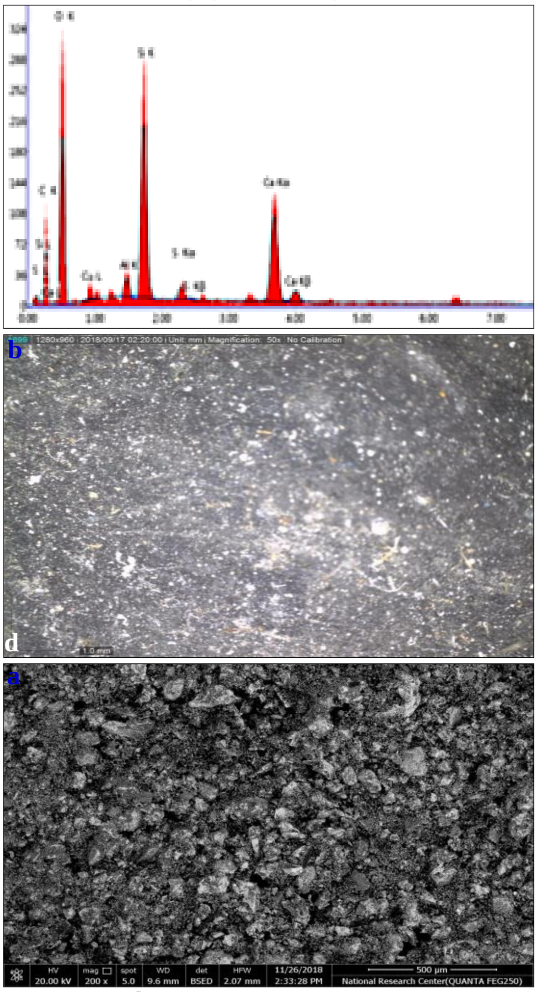


Figure (11) Shows **a.** **c.** EDX patterns of black color, **b.** USB photo, **c.** SEM photomicrograph of graphite grains.

3.3. *Gold layer*

XRD analysis tab. (1) of the gold sample taken from the rib cage piece, fig. (1-c "6") revealed that the gold layer consisted of a gold leaf (Au) and copper (Cu) [6, 20]. This result was confirmed by EDX, which showed the peaks of gold (Au) (65.93%), calcium (Ca) (15.52 %), iron (Fe) (2.56%), and oxygen (15.52%), fig. (12-a) & tab. (1). XRF analysis of the gold layer revealed that the layer consisted of Au, Ca, Fe, and Zn, fig. (12-b) & tab. (3). The investigation of the gold sample by LOM showed that the gold leaf was thin, and there were cracks in the gilding layer, fig. (12-c).

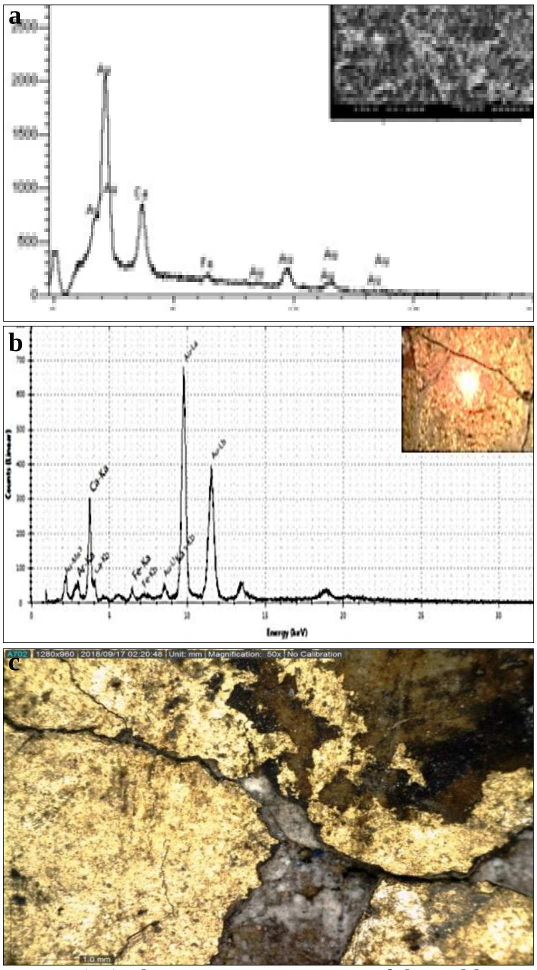


Figure (12) Shows a. EDX patterns of the gold sample, **b.** XRF result of the gilding layer, indicating Au and Fe, **c.** USB photo of the thickness and micro-crack of the gilding layer,

4. DISCUSSIONS

The present study characterized the composition of the pigments used in decoration. It could be concluded that all pigments found in the samples accorded with those used by Egyptian craftsmen during the

Roman Period. However, this multi-piece cartonnage included various and exceptional methods. Regarding the manufacturing technology, using textile in this cartonnage was unique, as it normally occurred as single or multiple layers throughout the cartonnage [20,28]. In this study, one layer of textile was made from a thick fiber to support some pieces (pectoral and foot pieces). However, other pieces used four layers of textile as support made from thin fiber. A different type was detected, consisting of a mixture of chopped flax fiber and chopped cereal straw [20]. The application of the preparation layer in this study was diversified. It used a technique of a single layer of calcite-based plaster mixed with gypsum and quartz in one layer in some pieces and two layers in other pieces. It was pretty common in the Greco-Roman cartonnage industry. It consisted of two layers: A coarse layer covered with another smooth layer prepared under the painting layer. The first coarse ground layer was composed of calcite ($CaCO_3$) with small amounts of quartz (SiO_2). The fine ground layer used under the pigments was composed of calcite ($CaCO_3$) only [12]. The results indicated that they mainly consisted of calcite ($CaCO_3$) based plaster and quartz (SiO_2) with some suggestion of the presence of kaolinite ($Al_4(Si_4O_{10})(OH)$ [3]. In some cases, small quantities of gypsum [20,29] or a mixture with huntite were identified [23]. This result also appeared when examining the preparation layer of the archaeological cartonnage found in Saqqara [24]. The results showed that this layer consisted of two layers: The first coarse ground layer consisted of a mixture of calcite and huntite, and the second or smooth layer consisted of white calcite only. In this study, the green color was used in two shades. Dark green, which consisted of Egyptian green, also called green frit, appeared shortly after Egyptian blue. The Egyptian green is a synthetic pigment produced at 1500 ^{o}C, making its properties diverse compared with Egyptian blue, although they have a similar compound. These two pigments have been confused for a long time [30,31]. The light green color in this paper was most probably malachite or verdigris in the green sample in the apron piece. Malachite was used as a green color and identified on the cartonnage from the Greco-Roman Period [3, 20]. The unexpected uses of Egyptian blue were detected here, in some pieces of this multi-piece cartonnage. It was an under layer or a subsurface paint below the red, yellow, and green pigments in the pectoral and foot. It was probably used as an atoning agent or a background to enhance the brilliance of the colors [27]. It might also be used as a darkener to modify the aspect of the other pigments. This technique introduced the wide availability of Egyptian blue during the Roman Period. It was abundant and could be a substitute for carbon black or chalk [32]. Egyptian blue in these pieces as an under layer might have been used earlier to color these parts. The current colors were added at a later period. In 3000 BC, Egyptian craftsmen created the first synthetic pigment. Egyptian blue "cuprorivaite" ($CaCuSi_4O_{10}$) minerals acted as the main coloring agent of the Egyptian blue pigment [30]. It was made by heating the mixture of calcium or limestone with copper compounds (oxides and cuprite or tenorite). The copper source for producing the Egyptian blue pigment was probably derived from copper ore, silica (sand), and flux in an oxidizing atmosphere at 850-1000 °C [33,34]. Egyptian blue was used as a blue color on the cartonnage from the Greco-Roman Period [23]. Cartonnage fragments from Hawara [12], gilded cartonnage from Saqqara [35], cartonnage fragments from EL-Lisht [36], Greco-Roman cartonnage [20], and a foot case cartonnage from the Late Period [15]. It was used as an under-drawing pigment to outline the face of some portraits during the Roman Period [29]. It was also used to produce different colors, for instance, admix with goethite to create green [25]. Sometimes, Egyptian blue was mixed with orpiment to have the green color [20]. Egyptian artists used blue cobalt in the Late Era (664-332) BCE [37]. Also, this color was detected on a mummy cartonnage from Saqqara [38]. Natural iron oxides occurred plentifully in Egypt. Then, anhydrous and hydrated oxides could be used as red pigments without any heat treatment [39,40]. Red ochre is characterized by the presence of the minerals of quartz and clay minerals. Calcite is associated with the hematite pigment mined in the Eastern Desert of Egypt during the Roman Period [22]. Red ochre was used to decorate a cartonnage from the Greco-Roman Period [23,34], a gilded cartonnage from Saqqara [33.34], and a Graeco-Roman Egyptian cartonnage [3,20]. Also, yellow ochre (gothite+ aluminum silicate) was used as a yellow color on this cartonnage and other instances from the Greco-Roman Period [20,26]. Yellow ochre mixed with orpiment was also detected on a Greco-Roman cartonnage [20,25]. Other instances used orpiment only as a yellow pigment on the Greco-Roman cartonnage [3,7]. The source of gold was most probably local because gold mines' exploitation in Egypt started as early as the Pre-Dynastic Period. Egyptian mines were discovered from the Eastern Desert down to Aswan [41]. The pure gold leaf on the orange pole was used to decorate the cartonnage from the Greco-Roman Period [20]. Gold was mixed with copper [6,36]. Graphite was used as black color in this cartonnage. Also, it was ordinary in the palette of the formerly studied cartonnage. Ancient Egyptians obtained black carbon from the soot deposition [36] Lampblack (carbon C) [3,12]. Ivory black [$Ca_3(PO_4)_2$+C+$MgSO_4$] [21] and charcoal black [23]. Magnetite (Fe_2O_3) was identified in the Greco-Roman cartonnage and consisted of a mixture of (FeO, 31.03 wt %) and hematite (Fe_2O_3, 68.97 wt %) [20]. It was mixed with other colors, such as red, to obtain brown [21]. Pigment samples had nearly comparable findings, indicating the existence of a tenacious binder, animal glue, with a long history of usage as a painting medium [42].

5. CONCLUSION

The present technical and analytical study was carried out on a painted and gilded cartonnage with multiple pieces taken from an unknown mummy dated back to the Late Greek-Roman Period at the Egyptian Museum's basement. The results of qualitative and quantitative methods, such as XRD, XRF, LOM, SEM, and FTIR, indicated that the cartonnage pieces consisted of three layers. The first was a painting layer consisting of a red pigment identified as Hematite Fe_2O_3, the yellow pigment was goethite (FeO(OH) in the pectoral piece, and there were goethite and traces of orpiment in the foot piece. The Egyptian blue (cuprorivaite, $CaCuSi_4O_{10}$) was used as an under layer in a unique technique in this object. It was used under the green, red, and yellow colors in pectoral and foot pieces. The green pigment was identified as Egyptian green in the pectoral piece, malachite, or verdigris (apron and rib cage pieces). The black pigment was identified as carbon black, and the gilding layer was identified as pure gold leaf applied on red bole that might be hematite (Fe_2O_3) according to XRF analysis and the presence of iron (Fe) and oxygen (O_2). The second layer was the ground layer composed of calcite ($CaCO_3$) as the major element with small amounts of quartz (SiO_2) and calcium sulphite ($CaSO_4.2H_2O$). The last layer was the textile support, which consisted of approximately one layer from thick fiber to four layers from the fine fiber. The fiber of support was identified as linen. The binding medium was characterized as animal glue in all pigments. The examination using (LOM) observed the change of canvas color to the yellowish color, which might be due to the thermal degradation of the canvas fibers and the discoloration of some pigments. SEM proved that the cartonnage was in a bad condition (detachments, losses, and cracks). Using SEM could show the extent of damage in all layers. The main reason for this damage was the bad conditions in the basement of the Egyptian Museum that lacked management and caused the complete loss of the objects. This study will help in the conservation plan for this object.

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