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A NON-DESTRUCTIVE ANALYTICAL STUDY AND THE CONSERVATION PROCESSES OF PHARAOH TUTANKHAMUN´S PAINTED BOAT MODEL

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Abstract

The boat model studied here belonged to Pharaoh Tutankhamun (1337-1347 B.C). It consists of several wooden pieces connected with different wooden joints and is decorated with painted layers. This study aims to use non-destructive analytical techniques in order to provide a deeper understanding of the painting and assembly techniques and to identify the wood species. Moreover, the authors were significantly interested in the condition of the object and the previous restoration interventions, so as to establish suitable treatment methods. Visual observation and assessment were done to understand the deterioration aspects, to be illustrated by a 2D Program, as well as the jointing methods, which were illustrated by the 3D.Max Program. Imaging techniques using IR Fluorescence and IR False Color, Optical Microscopy (OM), Environmental Scanning Electron Microscopy (ESEM), X-ray Diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR) were used in this study. Studies that include the identification of wood species and the characterization of pigments, as well as the previous restoration materials were made. The white layer of the boat cabin was confirmed to be in a deteriorated and unstable condition with many areas insecurely attached, with flaking and fragile areas. Other forms of damage included stains, splitting and separated pieces. Moreover, some parts had been wrongly assembled in the previous restoration interventions. Soon after its transportation from the Egyptian museum storage No 55 to the Wood Conservation Laboratory of the Grand Egyptian Museum-Conservation Center (GEM-CC), conservation techniques were applied with high accuracy, in order to conserve the object, including reattaching, lifting the white layer of the boat cabin, cleaning, removal of previous restorations, dismantling of the boat cabin panels and reassembly of the separated pieces, as well as filling cracks and separations. Finally, the conservation procedures that were applied were extremely effective for the stability and reinforcement of the boat model, which became ready for display or storage in the Grand Egyptian Museum (GEM).

Keywords: *Non-destructive; Model boat; Tutankhamun; IR luminescence; XRD; Conservation.*

Introduction

Religion played an important role in daily life in ancient Egypt, therefore the tombs were laid out very carefully with the most important items for the afterlife, such as a sarcophagus, washabties, scarabs, jewelry as well as model boats, which divided into rowing and small sailing boats [1]. The inclusion of model boats as a regular part of the burial assemblage first emerged in the late Old Kingdom and the First intermediate period; they were supposed to provide the deceased with a way of crossing the Nile to the netherworld, without having to rely

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on a celestial ferryman [2]. Model boats seem to have been the standard feature of 18th dynasty royal tombs and that of Tutankhamun, which was equipped with 35 models, ranging in length from less than 1m to over 2.5m. Eighteenh model boats were found in the treasury and the other model boats were found thrown higgledy-piggledy into the annex. The basic construction of each model is similar, consisting of a single block of wood or from a number of joined pieces of wood, then gessoed and painted and sometimes gilded [3].

The model boat under study (GEM. No 25) belonged to Pharaoh Tutankhamun (1337-1347 B.C - 18th dynasty - New kingdom). It was discovered in the corner of the treasury chamber, resting on chest and another boat was resting on it and hence it crushed the cabin (Fig. 1). It consists of hull body (high stem and stern from separate pieces of wood), steering paddles, central cabin and fore and aft 'look-outs' upon platforms (over hanging forecastle and poop decks). At the stern, the steering gear comprises a platform and two long broad bladed paddles (one of them was lost) which operate in upright crutches (paddle holder) and cross-supports (part of the poop deck). Both sides of the cabin have a door and two windows, as well as a cavetto cornice to both upper and lower Portions. The cabin outer walls were decorated with a chequer pattern [4]. After the discovery of the tomb, it was stored inside the Egyptian Museum storages (storage no 55). Then, it was transported to the Wood Conservation Laboratory of the Grand Egyptian Museum – Conservation Center (GEM.CC) in 2012. Its dimensions are about 93.4 cm in length, 18cm in width and 10cm in depth (Fig. 1C).

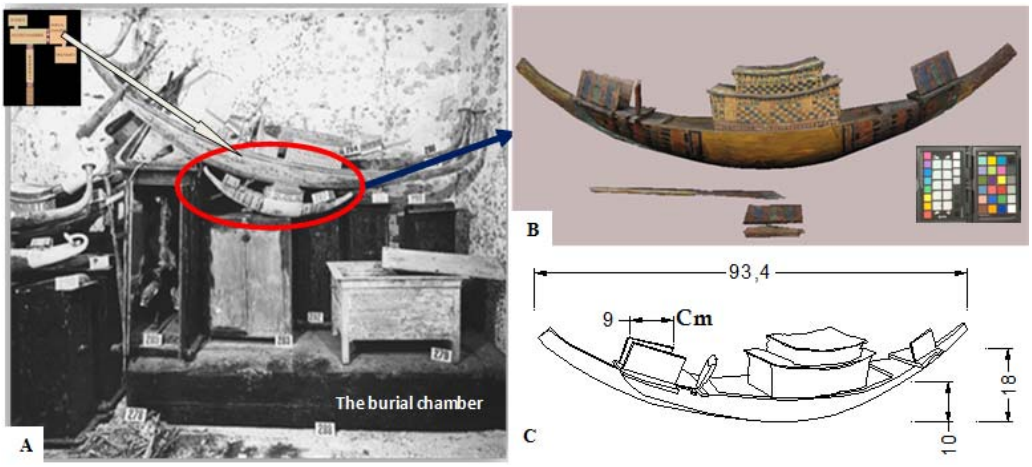

Fig. 1. The boat model: A - location inside the tomb, B - before conservation; C - the actual dimensions.

This paper aims to use non-destructive analytical techniques in order to provide a deeper understanding of the painting and assembly techniques and to identify the wood species. Moreover, the authors were significantly interested in the condition of the object and the previous restoration interventions, in order to establish suitable treatment methods.

In this work, Environmental Scanning Electron Microscopy (ESEM) and X-ray Diffraction (XRD) were used in laboratories, to directly analyze separated pieces from the external parts of the boat without altering them. After their study, the separated pieces were returned to their original location into the object.

Materials and methods

Visual assessment

Visual assessment by the critical eye of the team was performed, to determine the deterioration aspects of the boat model's wood and painted layers. This method is very effective

because the causes and mechanisms of deterioration may be easily identifiable. The critical eye of conservator can also determine the most effective techniques of analysis to be applied for identifying the condition of the boat under study.

Documentation of the boat model by utilizing software programs.

A Computer Aided Drawing program (2D) was used to illustrate the deterioration aspects for the model boat. A map of the damage was drawn for each side of the boat model and special key notes were made on every type of deterioration aspects. The 3ds.Max program was used to illustrate the jointing methods of the boat model.\

Imaging technique [IR fluorescence (IRF), IR False color (IRFC)]

Egyptian blue has luminescent properties. This luminescence cannot be seen in normal light conditions, but it can be detected and recorded by using a camera that is sensitive to infrared light. This phenomenon is called visible induced infrared luminescence [5]. The setup required for the imaging technique included a D90 DSLR (CMOS sensor) digital camera modified to “full spectrum” with a 90C IR Filter and a LED lamp to see the fluorescence (luminescence) and a X-Nite CCI filter for Visible (VIS) photography. The Infrared False Color image is made by digitally editing the VIS and IRF images using the Adobe Photoshop program. The copy of the VIS image was edited to become the IRFC image. The VIS green channel substitutes the blue channel and the red channel the green channel. Then, the IRF image constitutes the red channel of the edited VIS [6].

Optical Microscopy (OM)

For optical microscopy (OM) we used a Zeiss Stereo DV 20 (stereomicroscope) equipped with an Axio Cam MRC5 to investigate the surface morphology of the painted layers of the boat cabin. For transmitted light we used OPTKA MICROSCOPY (Italy) equipped with an OPTIKA B 9 Digital Camera to identify the wood species. Thin sections were obtained in the three principal anatomical directions: transverse (TS), tangential (TLS) and radial (RLS). The observation and description of the anatomical features for the sample were based on computer databases and wood anatomy atlases [7, 8].

Environmental scanning electron microscopy (ESEM)

A Quanta 3D 200i scanning electron microscope made by FEI was used for examining the cellular structure of wood and for studying the surface morphology of the painted layers used in the separated pieces. The accelerating voltage was between 10-15kV in the field of magnification orders of 400 to 800X.

X-ray diffraction (XRD)

Two separated pieces from the external parts of the boat model were analyzed by X-ray diffraction using X-ray Diffractometer System PW3040–Analytical Equipment– PANalytical pro model, Cu-target tube and Ni filter at 40kV and 30MA were used. (X’Pert Highscore) software was used for identifying the components of the painted layers.

Fourier transformed infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy was done using FTIR spectrometer (VERTEX 70, Bruker) equipped with An attenuated total reflection (ATR) in the 400–4000cm^{-1}, range with resolution of 8cm^{-1} to identify the previous consolidation materials.

Results and discussion

Deterioration aspects

Studying the condition of the model boat showed that the white layer of the boat cabin was in deteriorated and unstable condition with many areas insecurely attached, flaking and sometimes fragile. The flakes were distorted, their edges curling away from the wood beneath, thin and brittle and they tended to shatter when touched (Fig. 2A). Other forms of damage included dust, staining (Fig. 2B) and missing layers as well as the previous consolidation materials saturated the painted surfaces causing streaking and color change (Fig. 2C).While the

following deterioration aspects were noticed on the wood (Fig. 2D and E): cracks, splitting, separations and broken dowels; moreover, some parts were wrongly assembled in the previous restoration interventions.

Fig. 2. Deterioration aspects on the boat model: A - flaking; B - staining; C - previous consolidation materials saturated the painted layers; D - splitting and Separation; E - some parts wrongly reassembled and missing parts; F- fallen pieces.

Documentation of the Deterioration aspects

The condition of the boat model was recorded in detail and each part was carefully recorded using 2D program. This technique produced clear documentation of the deterioration aspects as shown in figure 3.

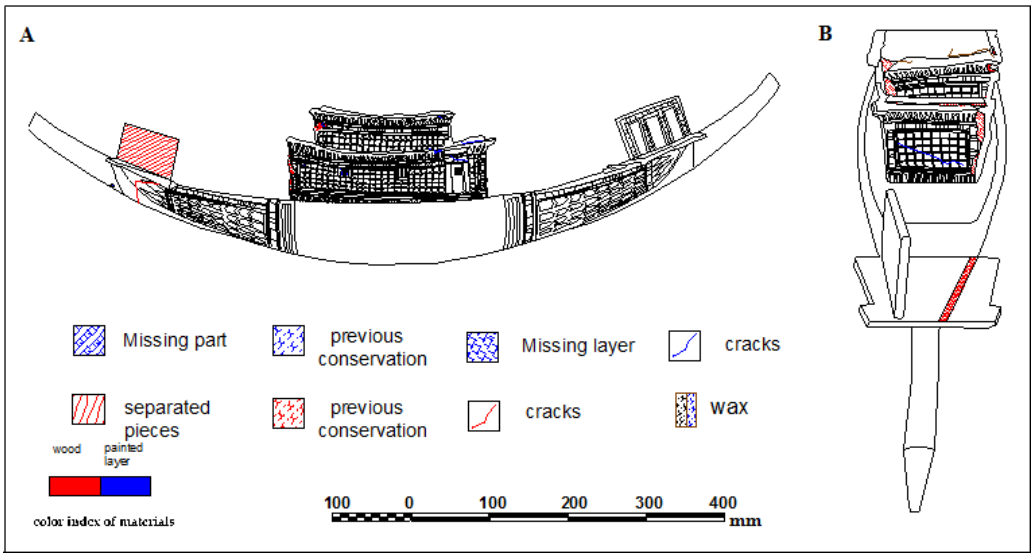

Fig. 3. Schematic Diagram of the boat model showing the deterioration aspects in 2D Program: A - Schematic Diagram of the right side of the boat model; B - Schematic Diagram of the back side of the boat model

Documentation of the jointing methods

Studying the jointing methods used in the boat model indicated that the body boat being connected to both stern and stem boat with spliced scarf joints and secured with dowels (Fig. 4B). The cabin, which is made from six pieces as walls connected together with metered finger joints (Fig. 4C) and three pieces as roof connecting to cabin walls without any joints, is fixed to the body boat by dowels. The fore and aft look-outs upon platforms connecting to the poop deck by dowels (Fig. 4D); moreover, each deck is fixed to stern and stem with dowels (Fig. 4E).

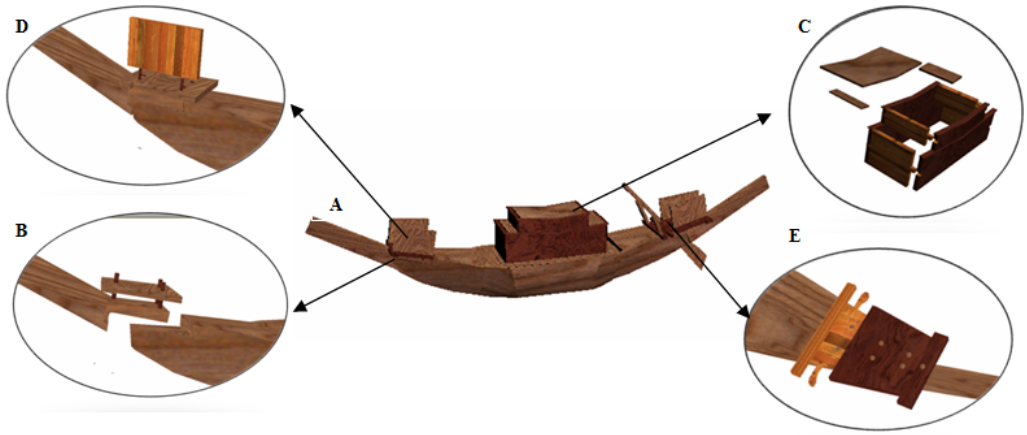

Fig. 4. Jointing methods used in the boat model by 3ds Max: A - General view for the boat model by 3d.Max; B - Boat stern connected to boat body with spliced scarf joints; C - Cabin walls connected together with metered finger joints; D -'look-outs' upon platforms connecting to the poop deck by dowels; E - poop deck is fixed to stern with dowels

Imaging technique [IR fluorescence (IRF), IR False color (IRFC)]

IR fluorescence (IRF) image showed that Egyptian blue was used in the areas that appear bright white (Fig. 5B), because these areas are showing visible-induced IR luminescence (in other words, they emit infrared light when excited with visible light), because no other pigment used by the ancient Egyptians has this property [9]. IR false color (IRFC) image showed that the areas painted with Egyptian blue appeared red (Fig. 5C) [10, 11], so we can say with certainty that these areas are painted with Egyptian blue using a completely non-invasive technique.

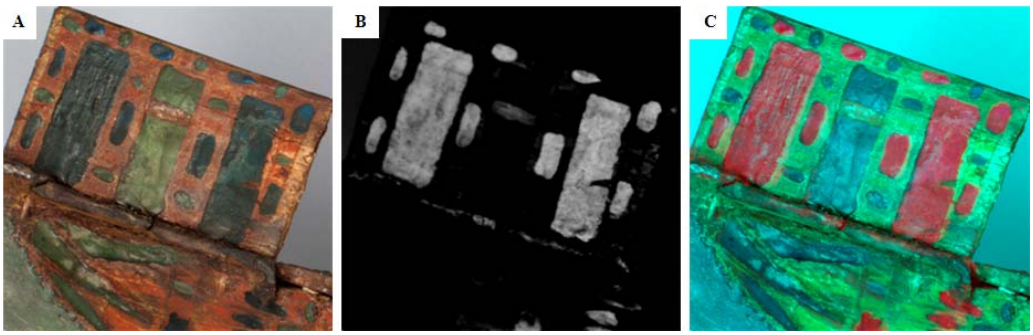

Fig. 5. The difference between VIS, IRF and IRFC images for the boat model: A - VIS; B - IRF showing Egyptian blue was used in the areas that appear bright white; C -. IRFC image showing the areas that appear red are where the Egyptian blue was applied.

Identification of wood species

OM micrographs showed that wood used in the right paddle holder was Lebanon cedar (*Cedrus libani*). This timber was used to make boat building and furniture as early as pre dynastic periods until as late as Greco –Roman times in ancient Egypt [12]. The diagnostic characteristics used to identify *Cedrus libani* were growth rings distinct and a gradual change from early wood to late wood tracheids as seen TS (Fig. 6A) [7]. Although not present in this specimen, it should be noted that cedar of Lebanon wood, can sometimes have arrow of tangentially orientated Traumatic resin canals which show up in TS [13]. Rays uniseriate and its average height is high to very height (more than 30cells in) as seen TLS (Fig. 6B) [8], ray tracheid commonly present with smooth cell walls and end walls of ray parenchyma cells distinctly pitted (nodular) as seen in RLS (Fig. 6C) [14] as well as scalloped torus margins of bordered pits present in the radial walls of tracheids, which are diagnostic of *Cedrus libani* as seen in RLS (Fig. 6D) [15]. Examination using SEM showed that the wood appeared to be in good condition, no fungal decay was evident and the cells were intact showing no signs of deterioration (Fig. 7A, B and C).

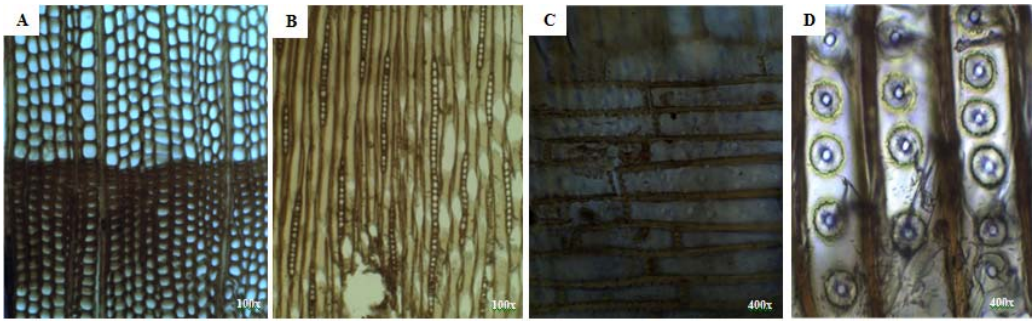

Fig. 6. The anatomical characteristics of *Cedrus libani* by OM in transmitted light: A - Transeverse section (TS) showing growth rings distinct, transition from early to late wood gradual; B -Tangential section(TLS) showing rays uniseriate and high to very high (more than 30 cells); C -Radial section(RLS) showing end walls and horizontal walls of ray Parenchyma cells distinctly pitted; D - Radial section (RLS) showing scalloped torus margins of bordered pits in the radial walls of tracheids, which are diagnostic of Cedrus libani.

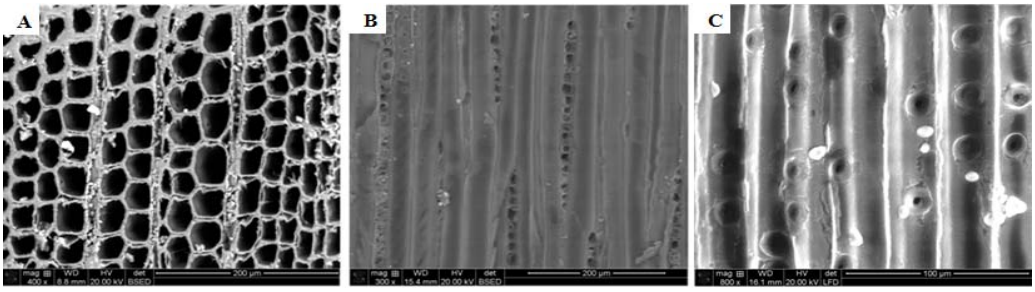

Fig. 7. SEM microphotographs of *Cedrus libani*: A -Transeverse section, B - Tangential section, C - Details of radial section showing no evident fungal decay and the cells were intact showing no signs of deterioration

Identification of painted layers

The preliminary observation of the boat revealed that yellow paint layer had been directly applied on the wood in most parts of boat (body and cabin) without any ground layer and white paint layer also applied directly on wood in the other parts. Outlines were executed in black paint, then red, green and blue pigments were applied last to decorate the boat model.OM examination for the painted surface of the cabin (Fig.8A - E) showed coarse morphology and

inhomogeneous composition of the pigment grains as well as the previous consolidation materials saturated the painted surfaces causing streaking and color change.

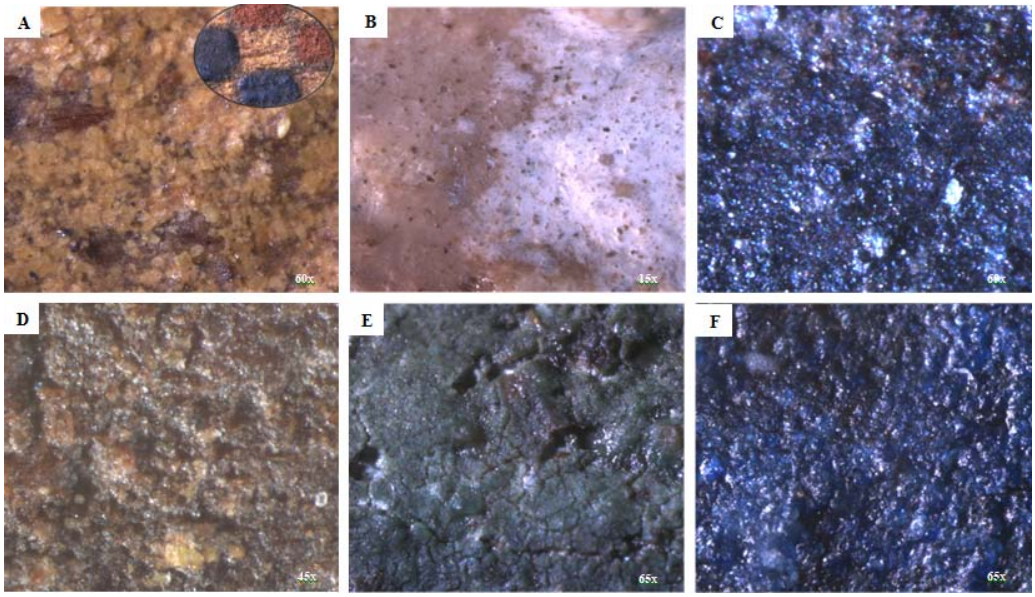

Fig. 8. Optical photomicrographs showing the course morphology of the painted layers surface used in the cabin: A - Yellow pigment; B - White pigment; C - Black pigment; D - Red pigment; E - Green pigment; F - Blue pigment.

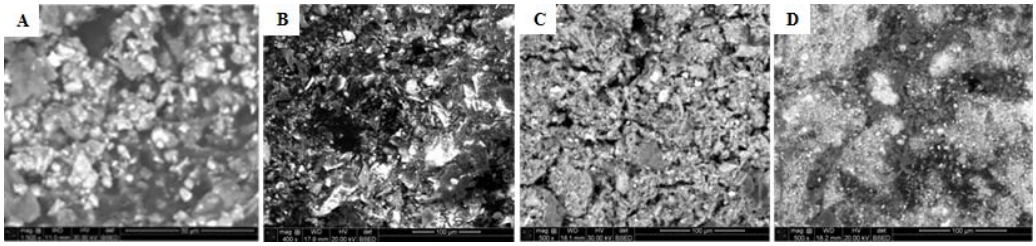

Fig. 9. SEM microphotographs of the painted layers used in the separated pieces: A - White pigment; B - Red pigment; C - Green pigment; D - Blue pigment.

1. *Yellow pigment*

We couldn't identify this pigment, as there were not enough fallen fragments of that pigment. OM examination (Fig. 8A) showed the rough morphology of the yellow surface, inhomogeneous distribution of the pigment grains and mostly applied directly on the wood without any ground layer.

2. *White pigment*

BSE photomicrograph of the white pigment surface used in the painted paddle holder (Fig. 8B) showed coarse morphology and inhomogeneous composition of the pigment grains.

XRD pattern in (Fig. 10A and Table 1) showed that the white painted layer was a mixture of calcite ($CaCO_3$) as main component with quartz (SiO_2), gypsum ($CaSO_4 \cdot 2H_2O$) and huntite ($CaMg_3(CO_3)_4$). Huntite was used from as early as old kingdom up to the roman period and became the predominant white pigment of the new kingdom for its brightness and whiteness [16].

3. *Red pigment*

BSE photomicrograph of the red pigment surface used in the painted paddle holder (Fig. 9D) showed coarse morphology and inhomogeneous distribution of the pigment grains which were coated with previous consolidation material. XRD analysis in (Fig. 10B and Table 1) showed that hematite is responsible for the red pigment in addition to the materials composition of the white layer underneath the red paint layer which contains mainly calcite mixed with quartz, gypsum and huntite. The majority of red pigments used in ancient Egypt were earthen based colors containing iron oxide, Especially, the mineral hematite (αFe_2O_3) was very common [17].

4. *Green pigment*

BSE photomicrograph of the green pigment (Fig. 9C) showed homogeneous distribution of the green pigment grains with micro cracks distributed on the entire pigment surface which was coated with previous consolidation material. XRD pattern of Green pigment as shown in (Fig. 10C and Table 1) revealed a mixture of wollastonite ($CaSi_4O_9$) and silica phases quartz and Cristobalite (the latter is higher temperature forms of quartz`), which characterized the Egyptian green, Beside the paraffin wax which was used as previous consolidation material by Lucas during the excavation of the tomb of Tutankhamun. The Egyptian green was developed during the proto and early Middle Kingdom (Dynasty 11) in ancient Egypt and was synthesized by firing a mixture of calcium, copper, silica and soda flux [18, 19].

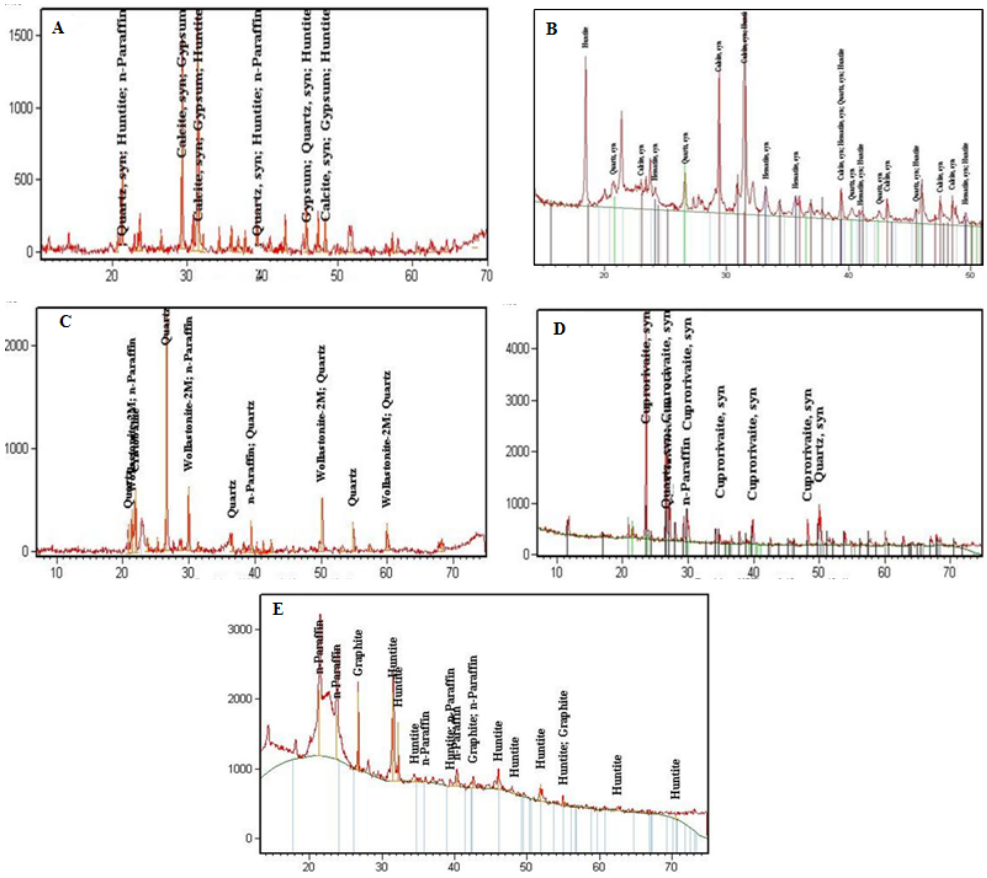

Fig. 10. X-ray diffraction pattern of pigments used on the boat model:
A - White pigment; B - Red pigment; C - Green pigment; D - Blue pigment; E - Black pigment.

Table 1 .X-Ray Diffraction results of pigments used in the model boat.

pigments	compounds
White	Calcite $CaCO_3$, Gypsum $CaSO_4 \cdot 2H_2O$, Quartz SiO_2 and huntite $CaMg_3(CO_3)_4$
Red	Calcite $CaCO_3$,Hematite Fe_2O_3, Quartz SiO_2 and huntite $CaMg_3(CO_3)_4$
Green	Wollastonite Ca Si_4O_9, Cristobalite SiO_2, quartz SiO_2 and paraffin wax $(Ch)^n$
Blue	Cuprorivaite $CaCuSi_4O_{10}$, Quartz SiO_2 and paraffin wax $(Ch)^n$
Black	Graphite C, huntite Ca· $Mg_3(CO_3)_4$ and paraffin wax $(Ch)^n$.

5. Blue pigment

BSE photomicrograph of the blue pigment (Fig. 9C) showed inhomogeneous composition of the pigment grains with fading of the color in some places and was coated with previous consolidation material. XRD pattern of the blue pigment (Fig. 10D and Table 1) showed the presence of Cuprorivaite ($CaCuSi_4O_{10}$) and quartz, which are responsible for the Egyptian blue [17], beside the paraffin wax. Egyptian blue was developed during the Old Kingdom (2600 BC) and used until the Roman period [19] as the first known artificially synthesized pigment. It was prepared by firing a mixture of compounds containing silicon (silica as sand), calcium (chalk or lime), a source of copper (copper minerals or bronze filings) and a soda flux [20, 21] ,which produces a heterogeneous product comprised predominantly of manufactured blue Cuprorivaite [22].

6. Black pigment

XRD analysis (Fig. 10E and Table 1) showed that the black pigment contains crystalline phase related to Graphite in addition to huntite which was used as white layer underneath the black paint layer. Paraffin wax was recorded which related to previous consolidation material. In almost every analysis of Egyptian pigments, black has proven to be carbon [17, 18,21].

Identification of the previous consolidation materials

FTIR spectrum of previous consolidation material (Fig. 11A) showed characteristic peaks of C-H stretching bands at 2916cm^{-1}, bending bands at 1472cm^{-1}and C-H torsion bands at 729cm^{-1}, which ascribed to paraffin wax [23] and this agree with the actual treatment records made by Lucas which verified that this boat was treated with paraffin wax [24].

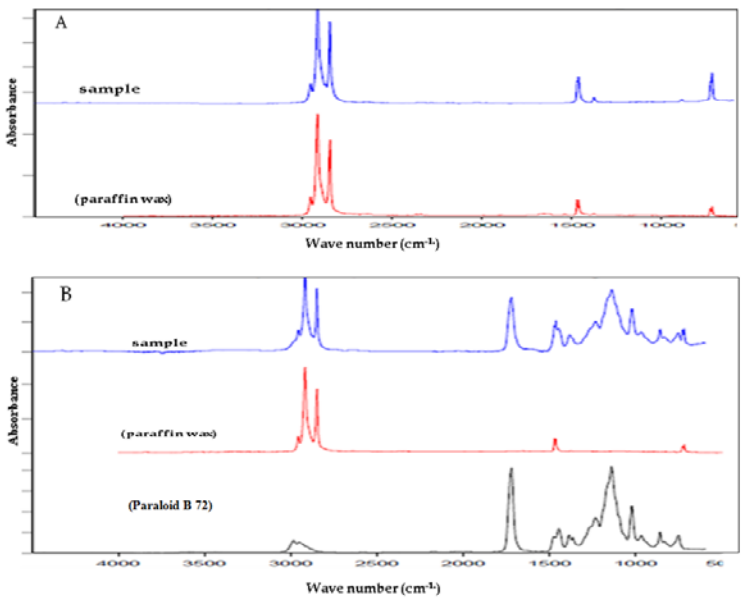

Fig 11. Comparing FTIR spectra between references and samples from two previous consolidation materials: A - previous consolidation material; B - previous adhesive material

FTIR spectrum of previous adhesive material showed characteristic peaks of C=O stretching group at 1721cm^{-1} ,C-O bending group at 1140 cm^{-1} and other peaks at 1023cm^{-1} and 2849cm^{-1}, which suggested that the material was ascribed to Paraloid B 72 [23] as well as some peaks at 2917cm^{-1}, 1473cm^{-1} and 728cm^{-1}, which ascribed to paraffin wax. This result was clearly verified by comparison with the reference samples of Paraloid B 72 and paraffin wax (Fig. 11B).

Treatment and Conservation

Different procedures for treating and conserving the studied boat model were employed as soon as it was transported to Wood laboratory of the Grand Egyptian Museum –Conservation Center (GEM.CC) entailed reattaching lifting white layers by setting it down and securing it in place with a dilute adhesive, cleaning, removal of previous restorations and dismantling and reassembly of the boat cabin panels as well as filling cracks and separations.

Fixing and reattaching lifting white paint layer of the boat cabin.

Based on the solubility tests, several consolidants were tested for stabilization of white paint layer. Paraloid B-72(ethyl methacrylate,/methyl acrylate co- polymer) in toluene, Plexisol P550 (butyl methacrylate) in toluene, Beva 371 (composed of a combination of ethylene vinyl acetate (EVA) resins with a variety of waxes and ketone resins) in toluene, Methocel (methyl cellulose) in water and Klucel G(hydroxypropyl cellulose) in ethanol [25]. The result revealed that (10 % w/v) Beva-371 in toluene was effective in the stabilization of white paint layer. Treated surfaces were gently pressed with silicon paper and heated micro-spatula (Fig. 12A and B) to manipulate the now slightly flexible lifted flakes back onto the support after Beva-371 had dried.

Fig. 12. Procedural steps of stabilization of white paint layer of the boat cabin:
A - During applying Beva-371 with brush; B - During pressing with silicone paper and heated micro-spatula;
C - During mechanical cleaning with a paintbrush

Surfaces Cleaning and Removal of previous consolidation materials

Loose dust was removed by gentle brushing and vacuuming with a low-power cleaner fitted with a flexible rubber nozzle (Fig. 12C). FTIR proved the previous consolidation material was paraffin wax, so mechanical methods e.g. Scalpel and dental tools were used to reduce paraffin wax then a cotton swabs immersed in toluene rolled over the uneven surface tended to remove it. Thin layer of paraffin wax on the painted layer had to be left in situ because it had become embedded in the paint layer and could not be removed without damage to the original pigments [26].

Dismantling and Reassembly of the cabin panels

Studying the condition of the boat cabin proved that the panels of roof cabin were wrongly assembled in the previous restoration interventions and FTIR analysis proved that adhesive used in the previous restorations for assembling the panels was Paraloid B 72. In order to reconstruct cabin panels in its original position, Acetone was used to assess the solubility of the previous adhesive material which achieved dismantling of the panels (Fig. 13A and B), then the panels of the cabin were re adhered in its original position with high accuracy using (40 %

w/v) Paraloid B -72 in acetone after cleaning the interior part of the cabin boat with vacuuming cleaner (Fig. 13C).

Fig. 13. Procedural steps for dismantling the panels of the cabin roof:
A - During dismantling the panels of the cabin roof; B - dismantling the panels of the cabin roof;
C - During mechanical cleaning for the interior part of the cabin boat with vacuuming cleaner.

Reassembly of the separated pieces

The separated look out piece was reassembled in its original position by insertion of a thin stainless steel bars into the broken dowels as follow: the diameter of the broken dowels was measured to select stainless steel bar with suitable diameter, then the drill was used to make holes for both sides of the broken dowels (Fig. 14A and B). After that a thin stainless steel bar (diameter: 1mm and length: 1.5cm) was inserted into the broken dowel holes of the separated piece using (40 % w/v) Paraloid B44 to be secured in its place (Fig. 14C) [2]. The separated paddle holder was re adhered in its original position using (40 % w/v) Paraloid B72.

Filling cracks and separations

Filling cracks and separations of the boat model depended on gap filling materials which were mentioned in recent literature [2, 26, 27]. In order to fill cracks and small voids between the wooden panels of the cabin, cotton fibers were applied, injected by Paraloid B72 (Fig. 15A and B) and then a fine putty consisting of 15% w/v Paraloid B72 in acetone, glass micro balloons and earth pigments was applied until the outer surface reached the expected level [26]. In order to fill the large separations between the wooden panels of the cabin, Balsa wood which is light weight and easily compressed [28], was prepared at the same size of the voids(Fig. 15C) and adhered with Paraloid B72, then the same previous putty was applied until the outer surface reached the expected level. In figure 16 is presented the model boat after the conservation.

Fig. 14. Procedural steps of reassembly of the separated loot out piece:
A - During making holes into the parts of the broken dowels by a drill;
B - After making holes into the parts of the broken dowels;
C - During inserting stainless steel bar into the broken dowel holes.

Fig. 15. Procedural steps of applying gap filling materials:
A - During inserting cotton fibres by spatula; B - During saturating cotton fibres by injection;
C - During preparing balsa wood for filling large separations

Fig. 16. The boat model after conservation

Conclusion

The boat model studied here belonged to Pharaoh Tutankhamun (1337-1347 B.C) and consisted of several wooden pieces connected with different wooden joints and decorated with painted layers. It was discovered inside his tomb in the corner of the treasury chamber, resting on a chest and another boat was resting on it, which caused cracks, splitting and separations of the cabin panels. Moreover, the white layer of the boat cabin was confirmed to be in a deteriorated and unstable condition, with many areas insecurely attached, flaking and sometimes fragile.Additionally, we found that the previous restoration interventions led to a saturation of the painted surfaces with the previous consolidation materials, causing streaking and staining and some parts were wrongly reassembled. Using 2D and 3ds Max Programs we produced a clear documentation of the deterioration aspects and the method of its manufacture in all parts of the boat model. Our imaging technique using IR fluorescence and IR False color is a rapid and low-cost method to identify Egyptian blue non-destructively. The painted layers were studied by optical and scanning electron microscopy, while their composition was determined by XRD. Based on the results of the analyses, we found that a mixture of calcite, quartz, gypsum and huntite was responsible for the white painted layer, hematite was responsible for the red pigment and the green pigment was Egyptian green, the blue pigment was Egyptian blue and graphite was responsible for the black pigment. Wood identification

results confirmed that the type of wood used was *Cedrus libani*. Our analysis using FTIR allowed us to characterize the materials added during the previous restorations, which helped us choose the most appropriate solvents and to decide how to dismantle wrongly assembled parts, which were reassembled in their original positions. Finally, the conservation procedures that we applied were extremely effective for the stability and reinforcement of the boat, which became ready for display or storage in the Grand Egyptian Museum (GEM).

Acknowledgments

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