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EXAMINATION AND ANALYSIS OF A PAINTED WOODEN FUNERARY STELA FROM THE LATE PERIOD AT THE EGYPTIAN MUSEUM IN CAIRO

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***Abstract**:*
This study presents the results of various analytical techniques applied to a painted wooden stela in the Egyptian Museum in Cairo. The examined elements of the stela included the wooden support, the prepared layer, and the various colors overlaying it. The techniques applied were the analysis of a cross-section from the wooden support using a USB digital microscope, Scanning Electron Microscope (SEM), X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy with Attenuated Total Reflection (FTIR), and Visible-induced Infrared Luminescence (VIL). The study also focused on the most active fungi that grow on the wood. The analysis of the pigments revealed the presence of Egyptian green and blue, hematite, calcium carbonate, and orpiment. These were applied on an orpiment background. An organic binder in the form of gum Arabic was detected, indicating the application of the tempera technique. The wooden support was made of sycamore wood. The preparation layer consisted of calcium carbonate with silicon as the base layer, followed by a layer of calcite.

1. Introduction

Many studies were conducted on round-topped stelae from different periods, including those made of stone and wood. Studies on stone stelae often focused on dating the object. One study was concerned with the description and interpretation of the hieroglyphs and the basis of the offering formula, design, layout, and inscription, dating the stelae to the late Middle kingdom [1,2]. Another example covered an analytical study of a round-topped limestone stela dated to the first half of the 2nd century BC, providing information on titles, society, and funeral aspects at that time [3]. There were also studies on round-topped stone stelae found at the north necropolis of Abydos belonging to a man called *ḏedqw* and his wife, *ḏedet*. The study included the workshop on Dedow's stela and revealed the stela, the way of inscriptions and scenes, and the poor style that indicated that the stela could be dated to the late 12th or early 13th dynasties [4,5]. Studies on wooden round-topped funerary stelae offered a brief description and discussed the iconography as a means of helping to date them to the 26th dynasty [6]. In relation to analytical studies on stelae made of wood, another study on the funerary stelae of the 26th dynasty examined why wood was used as a material for this object, suggesting reasons for the economy and the portability of wood versus the heaviness of stone [7]. The use of a lightweight material, such as wood, was perhaps preferred so that the stelae could easily be placed with the deceased, either near the coffin inside the burial chamber or elsewhere in the tomb [8]. While such archaeological studies were conducted on stone and wooden stelae, there were fewer diagnostic studies (examination and analysis). An exception was the study of a limestone stela from the Egyptian museum in Cairo dated to the 26th dynasty. It focused on the identification of the most active bacterial and fungal species that could grow on copper-based pigment materials (Egyptian blue and Egyptian green) and their role in the discoloration phenomenon of these pigments. It was discovered that the most active fungal species in both were *Aspergillus fumigatus*, *Aspergillus niger*, and *Aspergillus flavus*, while the most active bacterial genera were *Pseudomonas taetrolens*, *Bacillus subtilis*, and *Serratia rubidaea* [9]. The Egyptians regularly used sycamore wood for making objects, which was referred to frequently in ancient Egyptian records. In the 18th dynasty and 251 BC, it was mentioned for building boats, while in the 20th dynasty, it was used to make statues and was planted to make sycamore gardens. The tree itself was represented frequently on tomb walls of the 18th dynasty in Thebes [10]. Diagnostic studies on some sycamore objects were conducted, for example, on the goddess Bastet's wooden statue dated to the Late period. This study some used investigation techniques, such as Technical photography (TP), Optical microscopy (OM), Environmental scanning electron microscope attached with Energy dispersive x-ray analysis (ESEM-EDX), and Fourier-transformed infrared (FT-IR) spectroscopy to identify the materials of the statue. The analyses revealed the presence of six wood species, including Lebanese cedar, Sycamore, and Tamarisk, in the body of the statue [11]. A study of a wooden statuette of the god Ptah-Sokar-Osiris from the 26th dynasty aimed to identify the wood species and the painted materials layered on top of the wood, focusing on the surface texture of the painted preparation layers. The pigments used on the statuette were identified as hematite, Egyptian blue, arsenic sulfides, possibly malachite, and carbon from the charred animal origin [12]. In another study on polychrome painted wood coffins, such as the coffin in the Arizona State museum at the University of Arizona, USA, the wood was identified as sycamore [13]. Various analysis methods, such as FTIR, XRD, LOM, and SEM-EDX, were used on a polychrome painted wooden coffin for an unknown mummy of the late period discovered at Saqqara in 1958 for the treatment and conservation of the coffin [14]. The aim of this paper is to identify the materials used in making a wooden funerary stela dating back to the late period and define the deterioration factors that affected the wooden support and all the polychrome layers that covered the wood. It is common to find a microbial attack [15] or an insect infestation [16] in wooden artifacts. Yet, the process of covering wood with a white preparation layer can be considered the first stage of decay, especially when the particles of that layer may penetrate the wood cells or pores [17]. According to the Egyptian museum database, the wooden stela has the registration number JE 3394, SR 4/9408 and is dated to the 26th dynasty. Its length is 30 cm, width is 25 cm, and thickness is 2 cm. It was found in 1859 in Sheikh Abd el-Qurna on the West Bank, Luxor. The description given for the stela is divided into three parts. Part one (the top semi-circular part) is described as decorated with a winged sun disc and horizontal writing in hieroglyphs below the sun disc. Part two (the middle), the center of the stela, comprises the main section. Part three (the lowest) has a text containing three horizontal lines in hieroglyphs. The stela was in poor condition when it was found. There was loss in the wooden support, the layers of colors, and the preparation layer, with longitudinal cracks and disintegration, which are partly separated from the wooden support, fig. (1-a). There were also three holes in the back. In addition to the presence of dirt, fig. (1-b), the stela suffered from wood shrinkage, and its effects made it vulnerable to further damage.

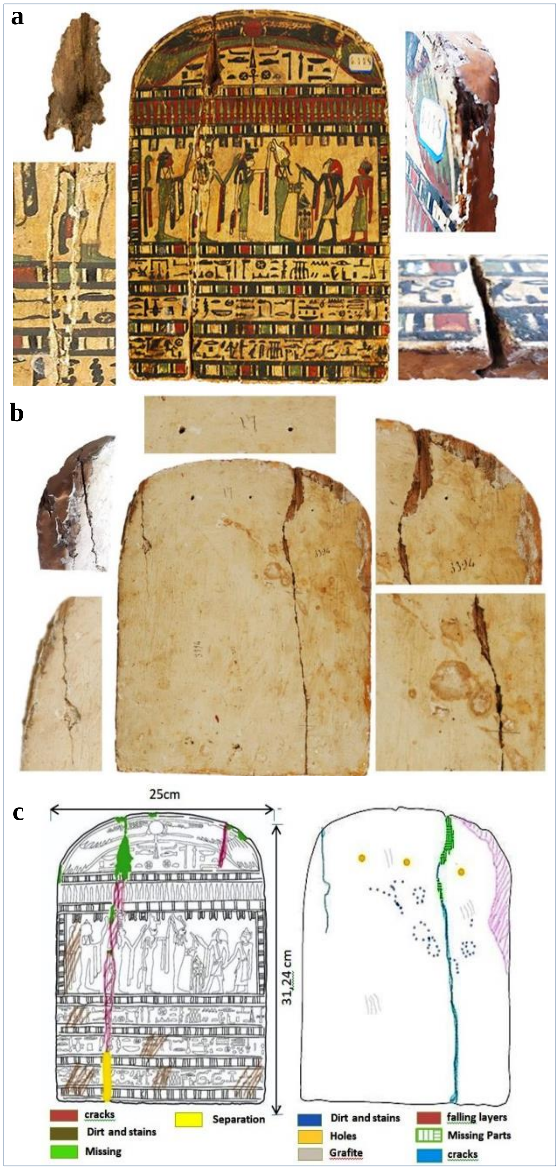


Figure (1) Shows **a.** & **b.** the stela from front and back, loss in the wooden support, loss in the layers of colors, the preparation layer, as well as the appearance of the wooden support, longitudinal cracks, disintegration, separation of the wooden support, and three small holes, **c.** & **d.** documentation of the degradation factors that affected the front and back of the stela.

2. Material and Methods

2.1. *Sampling*

Tiny samples were taken from an area of flaking paint; usually, a sample size of 1×2 mm is sufficient, yet extreme care should be taken [18].

2.2. *Methods*

2.2.1. USB digital microscope

Sensor**:** HD color Comos sensor, High speed DSP**,** Image resolution: Standard 640* 480* 5 Digital zoom, includes digital measuring sof-tware and calibration, ruler, Compatible, Highest 1600*1200, Focus range: 0-200 mm CPU 1G, RAM 128MB, HD Space 150 MB, VGA 16-bit, CD-ROM, USB 2.0/USB1.

2.2.2. Environmental scanning electron microscope (ESEM)

System resolution: 136 eV, Quantitative method: ZAF (2 iterations)

2.2.3. Visible-induced infrared lumines-cence (VIL)

A Dino-Lite digital microscope (IR-UV) provided with an IR cut-off filter and LED light

2.2.4. X-Ray fluorescence (XRF)

Pigments and layer preparation were analyzed with a portable XRF device at the museum conservation lab. It has the following specifications: Measurement time: 40.0 s, tube voltage: (40 kV), tube current: (20 µA), tube target material: (Rh), Elio device: (SN177), device mode: (head), acquisition mode: (manual), acquisition channels: (4096), and sample to detector material: (air)

2.2.5. X-ray diffraction (XRD)

Only plaster samples were analyzed on an XRD Philips Diffractometer Type (Pw1840) at 40 kV and 50 mA with CuK1 radiation (wavelength = 1.540562).

2.2.6. FT–IR analysis

A yellow powder sample was analyzed by FTIR. The potassium bromide (KBr) discs were analyzed in the transmittance mode using a Shimadzu (AA-6300) Fourier transform infrared spectrometer; it was operated in the mid-IR region (400-4000 cm^{-1}).

3. Results

3.1. *Wooden support*

3.1.1. A cross-section, longitudinal sector

A cross-section, longitudinal sector of the sample was examined under light microscopy (40-x magnification), fig. (2) and compared to the standard samples that indicated that the wood used was *Ficus sycomorus* [19]. Sycamore wood was used in the manufacture of statues and coffins. Although sycamore wood is a medium-quality wood that is susceptible to insect attack, it is easy to carve and shape.

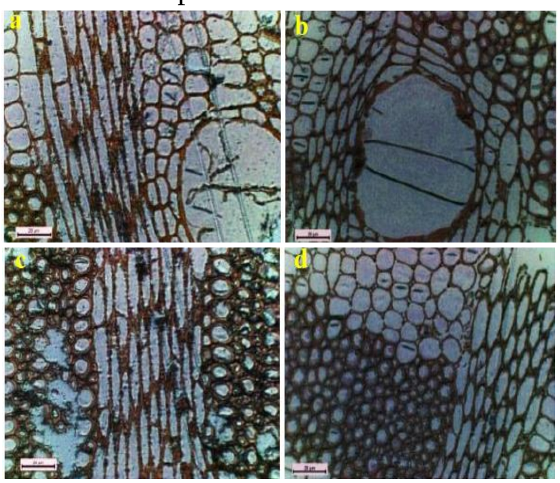


Figure (2) Shows **a.** & **b.** cross-section, **c.** longitudinal sector of the sample under LM (40-x)

SEM micrographs show particles of gesso layers between the wood cells fig. (3-a). This finding is similar to the results of a previous study that indicated that particles or minerals of the materials used in the preparation layer might penetrate porous wood species, such as sycamore [17]. The microbiological deterioration of this type of wood was also evident in micrographs, as the spores and the fungal hyphae appeared clearly in the images, fig. (3-b), a feature of decay that was commonly recorded in previous research [15]. We also noted the wood deterioration through the cross-section image, fig (3-c), which shows the separation of wood cell walls and the separation of the cells.

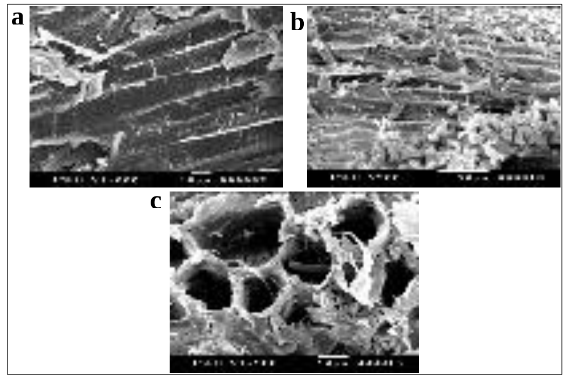
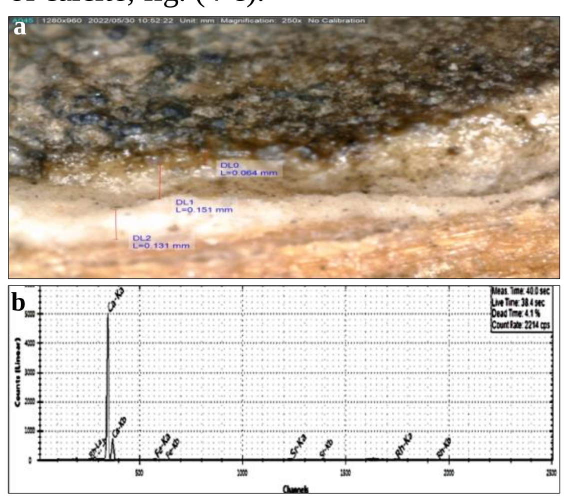


Figure (3) SEM micrographs; **a.** presence of gesso particles that penetrated the wood cells, **b.** fungal deterioration of wood, as the fungal spores and hyphae are clearly visible, **c.** cross-section of wood cells and the separation of the cell wall layers and the cells.

3.2. *Ground layer*

USB digital microscope examination with cross-section showed the application of two layers: a rough ground layer, then a smoothed ground layer to cover the wood defects, fig. (4-a). XRF analysis of the ground showed the components of the yellow consisting of a very thin layer of orpiment. The elements of the preparation ground, i.e., calcite and silica, iron, titanium, and strontium signals, were also observed. These elements can be found as common impurities in rocks used to prepare ground layers fig. (4-b). XRD analysis proved that the 1st coarse layer consisted of calcite and silica, fig. (4-c). The 2nd was a fine-grained layer composed mainly of calcite, fig. (4-c).



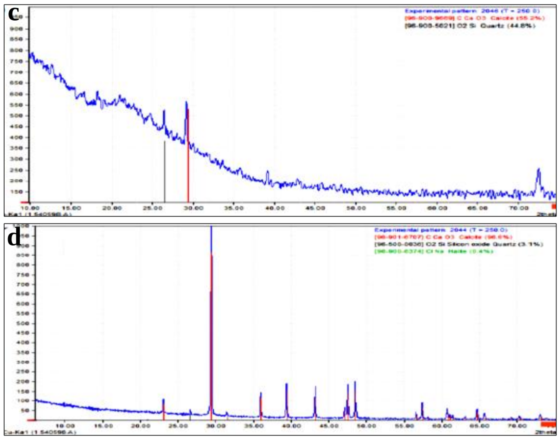
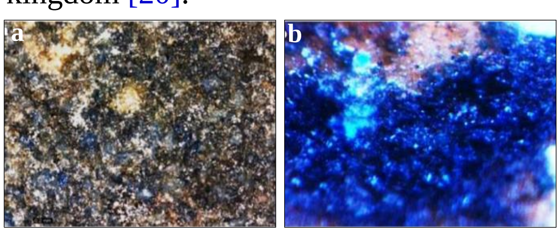


Figure (4) Shows **a.** the sequence of stratigraphy, **b.** XRF of the preparation layer reveals the components of calcite and silica, and XRD of the sample reveals that **c. the** 1st coarse layer consists of calcite and silica, **d.** the 2nd fine-grained layer is composed of calcite.

3.3. *Painted layer*

3.3.1. Blue pigment

USB microscope investigation showed a fairly thick, rough layer that contained a dark blue pigment and particles with different grain sizes. There was poor coverage of the painted material, which caused a loss of color in some parts and the appearance of the preparation layer, fig. (5-a). XRF analysis showed the elements of Cu, Ca and "Si", which is consistent with the characterization of Egyptian blue ($CaCuSi_4O_{10}$), fig. (5-b). Furthermore, it was confirmed as Egyptian blue by an Infrared fluorescence photography "IRF" VIL image, which showed the blue places appearing as bright white, while all other materials appeared dark. This case indicated the presence of Egyptian blue, fig. (5-c). The Egyptian blue might be used under the colors to enhance their brilliance. It was reported that light Egyptian blue pigment appeared during the 18th dynasty of the New kingdom [20].



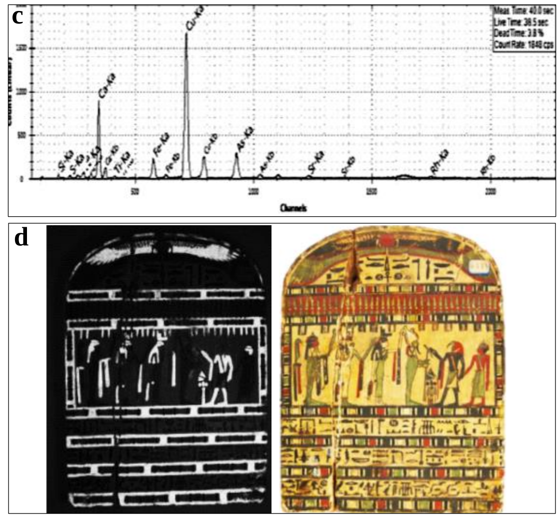


Figure (5) Shows **a.** & **b.** USB microscope of a rough layer, **c.** XRF of the preparation layer reveals the components of the dark blue pigment, **d.** "IRF" VIL image with blue parts appearing as bright white, while all other materials appeared dark, indicating the presence of Egyptian blue.

3.3.2. Red pigment

USB microscope showed a homogeneous, glossy, and saturated layer resulting from previous restoration processes, intense color, strong contrast between the sizes of grains, including grains of quartz, and some dark igneous rocks, fig. (6-a & b). XRF confirmed that it was ochre pigment hematite Fe_2O_3 as iron was higher than other impurities in the background and appeared clearly in comparison with other samples, fig. (6-c).

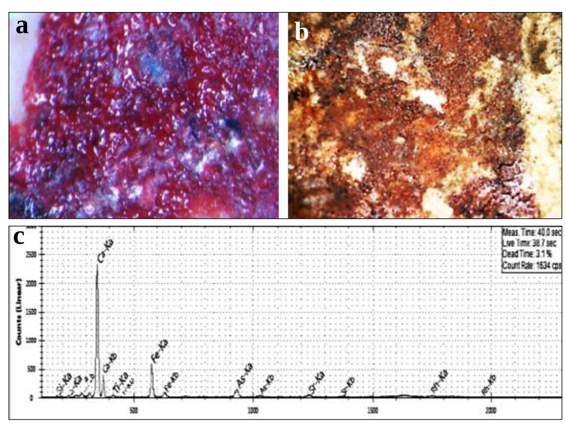


Figure (6) Shows **a.** & **b.** USB microscope image shows the preparation layer revealing components of a homogeneous, glossy, and saturated layer of red **c.** XRF of the same sample.

3.3.3. Green pigment

USB microscope showed coarse grains scattered in the matrix, a very shiny layer from the previous restoration process, in addition to micro-cracks, with some impurities and iron oxides with weak and fading color erosion. It also showed the loss of pigment in some places, which led to the appearance of the preparation layer, fig. (7-a & b). XRF revealed Cu, Si, and Ca elements, suggesting the use of Egyptian green pigment, fig. (7-c). It also illustrated other elements in the preparation layer and orpiment in the background.

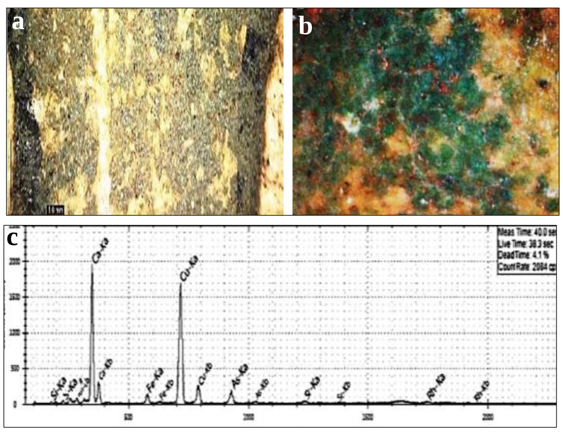
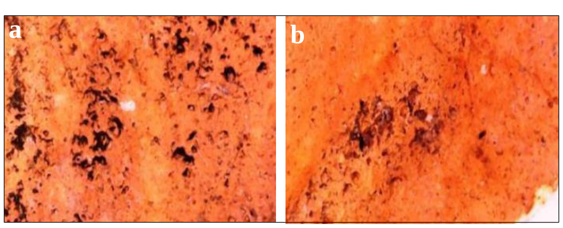


Figure (7) Shows **a.** & **b.** USB microscope shows coarse grains scattered in the matrix, a very shiny layer, and microcracks, **c.** XRF illustrates Cu, Si, and Ca, indicating Egyptian green.

3.3.4. Yellow pigment

The USB microscope revealed the poor coverage of the painted material, gaps, and voids in the painted layer, heterogeneity, and extreme grain size discrepancy, fig. (8-a & b). XRF showed the presence of orpiment As_2S_3, fig. (8-c).



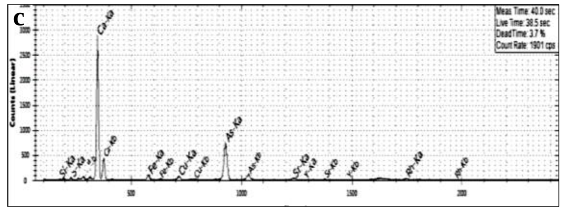


Figure (8) Shows **a.** & **b.** USB microscope image shows the poor coverage, gaps, and voids in the color, **c.** XRF shows As_2S_3 "As", which refers to orpiment.

3.3.5. Pale yellow pigment as a background

The USB microscope showed a very thin layer of light yellow areas, which were used as a background for all scenes, cracks with some impurities, and iron oxides with weak and fading color erosion, fig. (9-a & b). XRF analysis showed the presence of orpiment (As, S) that was used as a thin layer on the background. The percentage of arsenic (As) appeared less than that of the actual orpiment used in the scenes. XRF also showed the plaster elements represented by (Ca, Si, S), fig. (9-c).

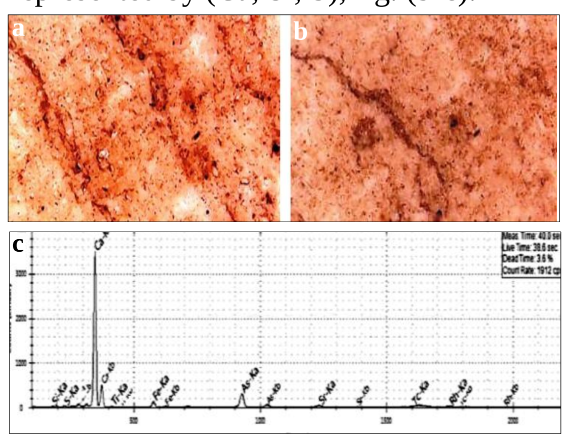


Figure (9) Shows **a.** & **b.** USB microscope image shows the poor coverage, cracks, gaps, and voids in the color layer, **c.** XRF analysis shows the orpiment (As, S) in tiny proportions that was used as a thin layer for the background

3.3.6. Organic binder

The FT–IR spectrum on the yellow paint sample demonstrated the presence of calcite as the preparation layer and the characteristic bands of an organic material tab. (1) & fig.

(10). The bands at 3400, specifically here at 3421 cm^{-1}, are for the hydroxyl group stretching (O–H). The bands at 2821-2956 are for the C–H stretching, and the band at 1659 cm^{-1} is for C=O stretching (carbonyl group). These bands express the presence of Arabic gum as organic media of pigments. The bands at 1310-1460 and 898 are associated with the carbonate group. This kind of gum is collected from the *Acacia senegal*, whose distribution covers Eastern Africa and the North of Sudan. Gum Arabic is a complex polysaccharide consisting mainly of galactose, arabinose, rhamnose, and glucoronic acid, with some protein content. The presence of an organic binder confirms that the tempera technique was used in this stela. In the tempera technique, the pigment powder is mixed with an organic paint medium, which allows adhesion between the pigment particles and the preparation layer.

Table (1) FTIR analytical results

S.	Functional group bands	Wave-number (cm^{-1})	Assignment
A	OH stretching	3421	Arabic Gum
B	C-H stretching	282-2956	Arabic Gum
C	C=O stretching as a shoulder	1659	Arabic Gum
D	CO_3 stretching + CH_2 bending	1310-1460	Calcite + Arabic Gum
E	O-C-O bending	898	Calcite

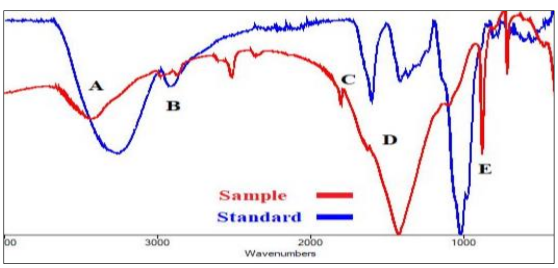


Figure (10) Shows the FTIR spectrum recorded on the sample (*compared with a standard spectrum of gum Arabic*).

4. Discussion

In the present study, after analyzing and scanning the deterioration aspects of the stela using the USB portable microscope, the investigation revealed the application of two layers in the background (a rough layer and then a smoothed layer to cover the wood defects [21-25]. A yellowish hue was added to the white ground layer. The investigation also revealed that the stela suffered from several manifestations of deterioration, including the separation of micro cracks, gaps, and voids in the color layer, and micro cracks. When looking at the interpretation of pigment results, the clear yellow in the scenes represented the same type of yellow pigment used in the background (orpiment As_2S_3**)** due to the intensity with which it appeared. The percentage of arsenic appeared higher than its presence in the thin layer used in the background. Orpiment is known to be used in Egypt no earlier than the 18th dynasty [24,25]. Being a naturally occurring arsenic sulfide, it produces a bright yellow color. Orpiment was widely used on a polychrome wooden artifact dating back to the 26th dynasty in ancient Egypt [12]. The blue color contained calcium and copper correlated with the existence of the mineral "cuprorivaite" ($CaCuSi_4O_{10}$), acting as the main coloring agent of the Egyptian blue pigment [26]. Lead (Pb) also appeared in the analysis, in addition to other elements in the background (calcium carbonate with silica). The background color is composed of "orpiment", to which the blue color was added on top. This pigment was made by mixing calcium salt (carbonate, sulfate, or hydroxide), a copper compound (oxide or malachite), sand (silica), and an alkali flux (sources of alkali could either be natron from areas, such as the Wadi Natrun and El-Kab or soda-rich plant ashes) [27]. It was the most well-known synthetic pigment in history, created by combining and heating (at around 850-950 °C) quartz, copper, calcite, and flux (alkali flux or plant ashes) [28]. The results of the red analysis also proved to be made of hematite Fe_2O_3, an ochre pigment that was by far the most commonly-used pigments in ancient Egypt and used from the pre-dynastic period onwards [29]. The analysis of the green color proved that it was made of Egyptian green, a synthetic pigment similar to Egyptian blue but based on silica-rich copper glass, and its manufacturing process requires higher temperatures and large amounts of alkali [30]. Consequently, the stela was a wooden support covered on all sides with a preparation layer of calcium carbonate with a percentage of silica. The scenes and the colors of hematite red, Egyptian green, Egyptian blue, calcium carbonate, and orpiment yellow were used to color the details and scenes of the painting.

5. Conclusion

Multiple analytical techniques, such as FTIR, XRF, and XRD, were utilized to determine the materials used to manufacture a painted wooden stela from the Egyptian museum. This stela is one of many very interesting late period wooden funerary stela in the magnificent collection of antiquities in the Egyptian museum in Cairo. The analysis indicated that the wood is sycamore; a lot of studies confirmed the use of this type of wood during this period. The preparation layer consisted of two layers; the 1st coarse layer consisted of calcite and silica, and the 2nd was a fine-grained layer composed mainly of calcite covered with the color layer. Previous studies confirmed that this method was used in polychrome wood, such as wooden coffins. According to previous studies on pigment layers on wood in the Late period, it was clear that the results of pigment analysis were similar to those identified in polychrome wood in ancient Egypt. The stela was covered on all sides with a layer of calcium carbonate with silica. As for the front part, which was used for the scenes and details of the painting, a thin layer of yellow orpiment was applied as a background for all scenes. The colors applied included black, hematite red, Egyptian green and blue, and calcium carbonate. Gum Arabic was used as a base binding medium for the pigments.

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