

DOI: 10.5281/zenodo.5717160

MULTI-INSTRUMENTAL INVESTIGATION AND ANALYSIS OF A UNIQUE ANCIENT EGYPTIAN WOODEN OBELISK (NEW KINGDOM) AT THE GRAND EGYPTIAN MUSEUM

Manar M. Elkhial^{1*} and Nesrin M. N. El Hadidi²

¹*Head of Fumigation and Environmental Management, The Grand Egyptian Museum, Giza, Egypt*

²*Professor of Wood Conservation, Faculty of Archaeology, Cairo University, Giza, Egypt*

Received: 13/08/2021

Accepted: 16/11/2021

Corresponding author: Manar Elkhial (manar_el_khial@yahoo.com)

ABSTRACT

An ancient Egyptian wooden obelisk heavily invaded by insects has been received at the Fumigation Laboratory at the Grand Egyptian Museum. The conservation treatment presumed conducting a modified atmosphere treatment for pest control and some stabilization interventions, thus, certain physicochemical tests were necessary. The multi-instrumental investigations and analyses conducted included optical microscopy (OM), digital microscopy (DM), technical imaging (TI), and X-ray fluorescence spectroscopy (XRF) to identify the wooden substrate and pigment traces. The aim was to identify the constituents of the obelisk to undertake the minimal necessary interventions and to stabilize its state of conservation using the most suitable intervention materials and techniques. Archaeological background, historical significance, and manufacturing technique of obelisk was reported. Results showed that the obelisk was made of Greek juniper (*Juniperus excelsa*) wood and contains traces of white pigment identified as gypsum, blue pigment identified as Egyptian blue, and black pigment identified as bone ivory.

KEYWORDS: Obelisk, Grand Egyptian Museum, investigation and analysis, new kingdom, XRF, digital microscopy, juniper wood, technical imaging

1. INTRODUCTION

The ancient Egyptians left the most wonderful and greatest civilizational legacy among peoples, the most of which were the obelisks and the pyramids, both symbolize the sun (God Ra) (Cooper, 1877). The obelisk is a distinctive characteristic monument in Egyptian civilization. It was called *tekhen* (Curran, 2009), *tekhen* (Cooper, 1877), or *teknu* (West, 2019) by ancient Egyptians, *obeliskos* (Baker and Baker, 2001) by the Greek, *needle* (Budge, 2003) by the Europeans, and *masalla* (Tassie et al., 2015), *mislal* or *missala* (Curran, 2014) by the Arab. In the ancient Egyptian civilization, the obelisk is a religious symbol. It either signifies the rising of the sun (Cooper, 1877) or the Djed pillar of Osiris (West, 2019), powerfully symbolizing rebirth and later stability. The obelisks date back to the prehistoric period (Cooper, 1877), but first appeared in Egypt during the Old Kingdom (Curran, 2009). However, Egypt was one of the most famous places of obelisks in the ancient world, as obelisks were found in many Egyptian cities, such as Heliopolis, Alexandria, and Luxor. An obelisk is a monolithic quadrangular structure having four faces usually inclined towards each other (Cooper, 1877) or are parallel to each other, with a pyramidion *benben* at the top (Sorek, 2010) with its faces tapering to a pyramid-shape top (Baker and Baker, 2001), usually inclined by sixty-degree angles (Cooper, 1877). The obelisk generally has a four-sided square base to act as a support (Cooper, 1877; Sorek, 2010). The obelisk could be inscribed or uninscribed. Inscriptions are always vertical (Cooper, 1877). The inscriptions on the quadrangular structure are usually related to or about the king, the owner, or the God it is erected for.

The obelisks were usually used in pairs in front of the temples as aesthetic elements, to decorate the entrance of the temples and memorials to commemorate the king or God. The Egyptian obelisks were generally made of hard stones, such as granite – especially red granite and sandstones (Cooper, 1877). The pyramidion was usually covered with bronze (Cooper, 1877), gold, or gold alloys (Obelisks in ancient Egypt, 2003). The Egyptian obelisks varied in size (Curran, 2014), from great obelisks and major obelisks to smaller obelisks found at lesser shrines and at tomb-chapels, and miniature scale as amulets (Obelisks in ancient Egypt, 2003).

Recently, the Grand Egyptian Museum (GEM) received a unique small wooden obelisk that dates back to the New Kingdom in Egypt- no exact dynasty was

mentioned - to be conserved and prepared for storage. GEM comprises a number of stone obelisks, which are incomplete, or heavily damaged. This obelisk is the only wooden model comprised by the GEM, which is found intact. Unfortunately, it is heavily deteriorated due to an insect attack that resembles itself in a variety of infestation signs. At the Fumigation Laboratory, the disinfestation technique is based on the use of inert gases, such as argon, nitrogen and carbon dioxide (Elkhial and Kamal, 2018). The selection criteria among these gases, are dependent on many factors; however, the selection is closely linked to the composition of the artifact to be treated; as some materials, pigments, dyes, etc. are susceptible to some inert gases (Koestler et al. 2004, Unger et al. 2001, Elkhial, 2019). As a primary observation, it was clear that the obelisk contains traces of pigments, which might be adversely affected by some inert gases used in modified atmosphere treatments. To assist in making objective decisions about the most suitable inert fumigant for the modified atmosphere treatment, identification of the constituents of the infested artifact was necessary. The level of conservation interventions and the selection of conservation materials for an archaeological object is also based on understanding its composition and degree of degradation (Khasawneh and Elserogy, 2019). This study, therefore, focuses on the multi-instrumental investigations of the obelisk in order to: 1) understand the historical context of the obelisk under study especially as it is a one-of-a-kind object at the GEM, 2) discern the composition of the trace pigments in the obelisk and 3) identify the species of wood of which the obelisk was erected. To reach these objectives, a multi-instrumental approach employing optical and digital microscopy, technical imaging and portable X-ray fluorescence was conducted.

2. THE WOODEN OBELISK UNDER STUDY

According to the data provided from the Artifacts and Information Affairs Department (AIAD) at the GEM, obelisk's current location, the object is a wooden obelisk with inscriptions under GEM No. 51297, SR No. (4) 8705, and TR No. 4/12/24/3. The provenance of the obelisk is unknown, and the former location is Cairo-Egyptian Museum (EM), Egypt, and it dates back to the New Kingdom. The artifacts registration book at the EM mentions that the object is "*an obelisk carrying on the anterior face and the lateral faces, a column of hieroglyphs, slightly hollow and hard to read*"¹.

¹ The text is translated from French. Original text is "Obélisque; portait sur la face antérieure et les faces latérales, une colonne de hieroglyphs, en léger creux, difficile à lire".

2.1 GENERAL DESCRIPTION

The object is a tall, four-sided obelisk carved from a single piece of wood. The base of the obelisk is missing and replaced with a new one probably during a former conservation intervention. The body of the obelisk is quadrangular with a small protrusion at the base and a pyramidion (*Benben*) at the top. The small protrusion acts as a tenon to fix the obelisk to its base. The pyramidion is deteriorated missing its apex. The

three sides of the obelisk's quadrangle are embellished with inscriptions and pigment traces. The decorations are restricted to a single longitudinal column of text extending down the pyramidion and terminating at the base of the obelisk. The text is carved in hieroglyphs surrounded by white borders. The hieroglyphs are vertically oriented and the text column is bounded with two margins (right and left) painted blue; each is bordered with two black lines. Figure 1 shows overviews of the four sides of the obelisk, and the top and the bottom views.

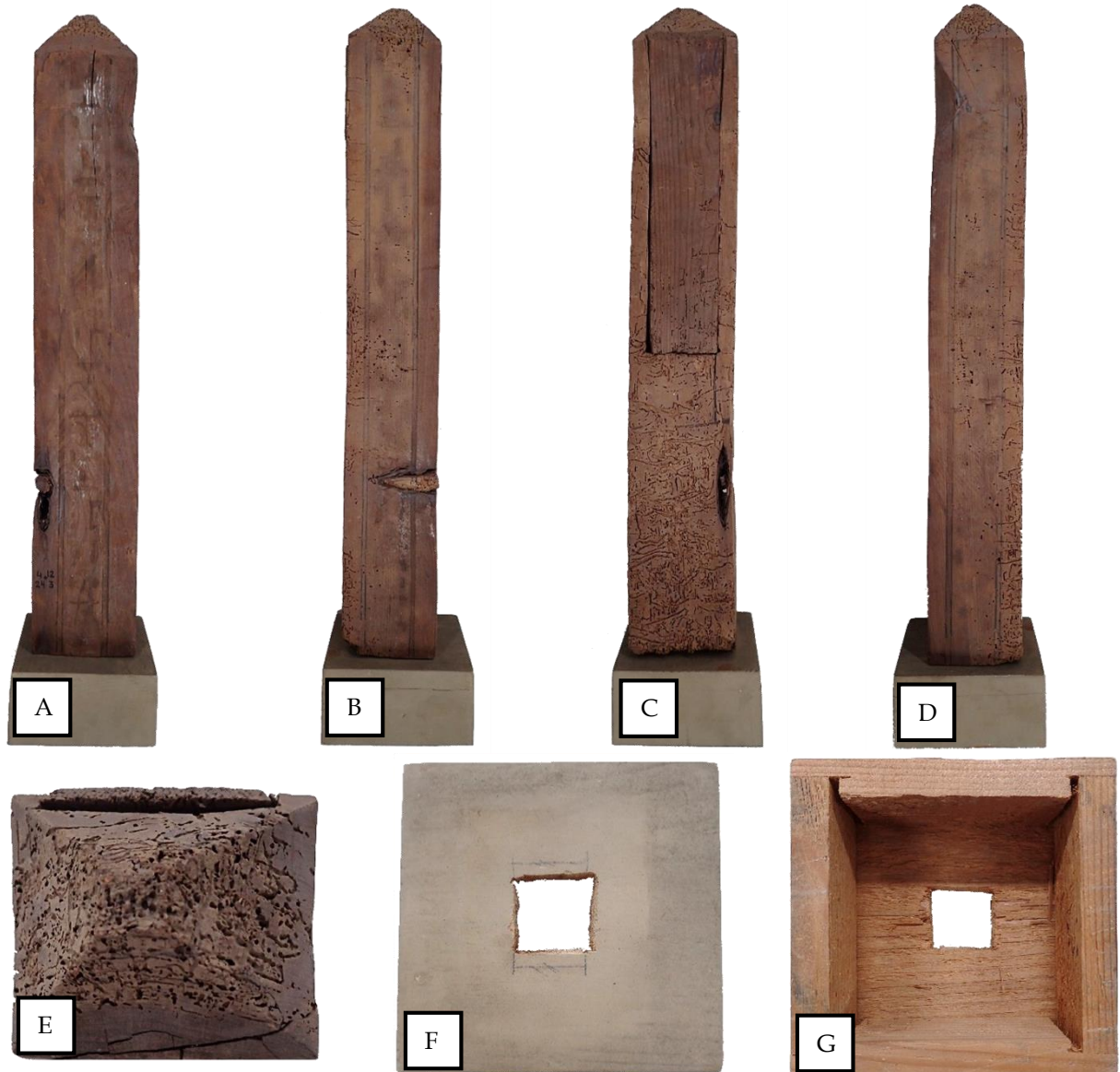


Figure 1. Overview of the obelisk; A: anterior side, B: right lateral side, C: posterior side, D: left lateral side, E: top view of the pyramidion, F: top view of the new base, and G: top view of the bottom of the new base.

2.2 OBJECT'S DIMENSIONS

The obelisk measures 46 cm from the deteriorated apex of the pyramidion to the protuberant end. The width of each two parallel sides is equal. The width of the anterior and posterior sides is equal to 7 cm, and

that of the lateral sides is equal to 6.4 cm. The pyramidion's base is 9.75 cm X 9.5 cm. The tenon fixing the obelisk to the wooden base is 1.88 cm long and its quadrangular base measures 2.20 cm by side. Figs 2 to 4 show in detail the dimensions of each part of the obelisk.

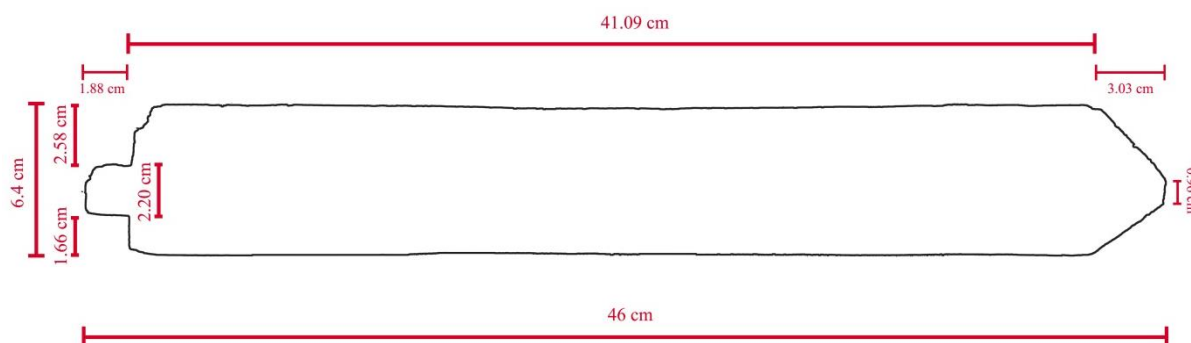


Figure 2. Outline map of one side of the object showing its dimensions.

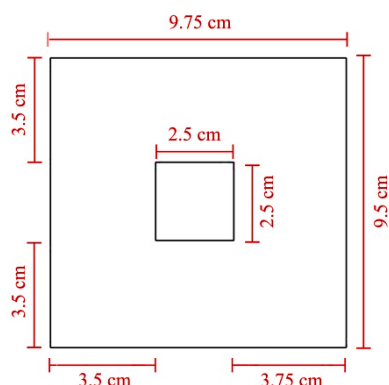


Figure 3. Outline map of base of the object showing its dimensions.

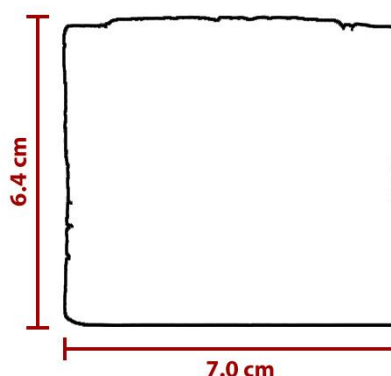


Figure 4. Outline map of the top of the object showing its dimensions.

3. MATERIALS AND METHODS

The obelisk was generally investigated visually. Optical Microscopy (OM) and Digital Microscopy (DM) were utilized to examine the object's composition (trace pigments) and identify wood. A combination of Technical Imaging (TI), X-Ray Fluorescence (XRF), and DM was adopted to further identify the composition of the trace pigments as a very efficient and non-destructive method for pigments identification (Abdallah *et al.*, 2020). Technical imaging was also employed to reveal the illegible text on the obelisk's four sides.

The examination techniques conducted in this study are completely non-destructive, but the examination was undertaken by subjecting the object directly to the examining beam and collecting results. In one case, a very small sample was taken from the deteriorated part of the object for wood identification.

3.1 Visual Assessment

The obelisk was examined visually by the critical, unaided eye and in some cases with the help of simple lenses and light torches. The examinations were documented photographically using Olympus Tough TG-2 12-megapixel camera (Olympus, Tokyo, Japan), with a 25-100mm equivalent zoom lens with a maximum aperture of $f/2.0$ at the wide-angle end. This camera has a telemacro mode which, when combined with a subject distance of 1cm, effectively turns the camera into a digital microscope.

3.2 Multi-Instrumental Investigation and Analysis

3.2.1 Optical Microscopy (OM)

The OPTIKA transmitted light microscope equipped with OPTIKA B 9 Digital Camera was used

to identify the wood species, through studying the wood thin sections manually obtained in the principal anatomical directions, transverse (TS), tangential (TLS), and Radial (RLS).

3.2.2 Digital Microscopy (DM)

The versatile Dino-Lite AD4113TA-I2V with 10x~300x zoom magnification and Infrared (IR) (940nm) + Near Ultraviolet (UV) (395nm) LEDs, a 1.3MP color CMOS sensor, and MicroTouch image capture and accessorized by MS35B Rigid Desktop Precision Rack, DinoCapture 2.0 software, version 1.4.2.D (AnMo Electronics Corporation, Taiwan) was used to examine the object's surface, pigment traces and the deep holes using three light zones (Visible, IR and UV).

3.2.3 Technical Imaging (TI)

After visual and optical examination of the object, technical images were acquired by employing visible (VIS), visible-induced ultraviolet luminescence (UVL), ultraviolet reflected (UVR), visible-induced infrared luminescence (VIL), and infrared (IR) imaging as an approach to identify pigments (Delaney et al., 2005; Cosentino, 2014; Elkhial, 2019), visualize texts, and enhance the readability of texts (Easton et al., 2003; Lettnery et al., 2008; Elkhial, 2019). In addition to the before-mentioned technical images, another image was also generated, IR false color, through processing the VIS and IR images. Technical imaging is generally a non-destructive way of examining cultural objects.

3.2.3.1 Technical Imaging Equipment

The technical images were acquired with a Nikon D90 DSLR Single-lens reflex digital camera (36.3 MP,

CMOS sensor, Nikon Inc., USA) modified for "full-spectrum"; ultraviolet-visible-infrared photography (between about 360 and 1100 nm); and equipped with Nikon AF-S NIKKOR 18-55mm f/3.5:5.6G AF lens, standard photography lens. The X-rite Color Checker Passport was used for color correction as a reference alongside the object. Every camera option was operated manually and the camera was tethered to a computer to allow sharp focusing in non-visible modes (IR and UV) using live view mode. The camera was calibrated with the X-rite Color Checker Passport (X-Rite Inc., USA) and its bundled software to create a camera profile for Adobe Camera Raw. The images were shot RAW and were then color corrected, using the camera profile, and white balanced (Cosentino, 2014; Elkhial, 2019).

For each technical image, special light sources and filters were used. Table 1 summarizes the light sources, filters, spectrum measuring range, and assigned color category for each technical image.

Acquired technical images were processed using the powerful, reliable, and advanced image editor Adobe Photoshop CC for Windows Version 22.4.3 which provides support for RAW image formats which makes it fully capable of working with RAW images using Adobe Camera Raw. The software was used to color correct the images using the camera profile, white balance them, and produce the jpg final files.

3.2.3.2 Technical Imaging Workflow

The workflow described in Cosentino (2014) and Elkhial (2019) in detail was followed to obtain five distinctive images for each side of the object in addition to a sixth processed image (IRFC).

Table 1. Summary of the equipment, light ranges, and interpretation guide for each imaging technique.

Image	Light Source	Filter	Wavelength (nm)	Assigned Category
VIS	two light-emitting diode (LED) lamps, positioned symmetrically at approximately 45°.	X-Nite CCI	380- 740	White, black, blue, none.
UVL	Two UV 365nm LED lamps.	UV/ IR Baader filter + X-Nite CCI	365	None (no fluorescence), white or medium purple, black.
UVR	Two UV 365nm LED lamps.	A Schneider W 403 + X-NiteCCI	365–400	Bright, dark.
VIL	two LED lamps.	Schott RG840 cut-on filter.	850–1000	Bright, none.
IRR	two LED IR lamps.	Schott RG840 cut-on filter.	850–1000	Bright, dark.

3.2.4 X-Ray Fluorescence (XRF) Spectroscopy

A hand-held XRF spectrometer Niton™ XL3t XRF analyzer (Thermo Fisher Scientific Inc. (NYSE: TMO), USA) was used to identify the elemental composition

of the pigment traces. This spectrometer uses a miniaturized low-power X-ray tube, which enables one to carry the spectrometer anywhere and perform on-site analysis easily (Ida, 2005). It has a tube of 50kV maximum with an anode of Au and a high-performance

semiconductor detector. It allows various modes compatible with the application, and convenient monitoring to the tested point thanks to its adjustable angle, color, liquid-crystal display (LCD) touch-screen. It has lower detection limits for higher-Z elements, with additional elements Mg, Al, Si, and P via helium purge. It allows analyzing a small area, as it has a user-selectable 3mm small spot to locate areas of interest on a sample. This instrument was adjusted to measure in the mining mode to permit the detection of most pigment elements, and it was used directly in situ (Elkhial, 2019). All measurements were performed in the air for 100s. Data were collected from the instrument using Standard Thermo Scientific™ Niton Data Transfer (NDT™) software and graphed using Microsoft® Excel 2019.

4. RESULTS AND DISCUSSION

4.1 Revealing the Hieroglyphic Inscriptions

The hieroglyphic inscriptions of the obelisk occur on three sides: the anterior, right lateral and left lateral side. They were vertically carved as text columns (one running from up to down in the middle of each side) with no pigments detected during investigation, except for some trace white color surrounding the shape of some hieroglyphic symbol. The column runs from the pyramidion base to the obelisk's feet. So, the

text is to be read from up to down. The text is generally damaged and illegible.

Technical imaging allowed for having clearer representation of the hieroglyphic symbols in UVL and IRR images. JSesh software Version 7.5.5 (Rosmorduc, 2014), the most widely used word processor in Egyptology (Polis and Winand, 2013; Iglesias-Franjo and Vilares, 2016) was utilized to restore the image by decoding the symbols, transliterating and translating them.

Fig. 5 shows the original text columns and their transcriptions with respect to their original orientation.

Understanding the translated text, the inscriptions on this obelisk comprise a conventional offering formula, which had become common since the Middle Kingdom (Collier and Manley, 2003) and was found in funerary objects in ancient Egypt followed by the name of the deity.

The text on the obelisk is an offering, which was given to Osiris the joyful, foremost of the west, the great god, lord of the necropolis, praying that hand might be given among the gods (to) "Wahebre".

Given the above, the function, as well as the owner of the obelisk indicates that the obelisk was used as a funerary offering to God Osiris and its owner is *Wahebre*.

	Transliteration <i>Im3hw hr Wsir, ntr-ꜥ3, hꜥ3-dt, hnk.f hr(?) ntrt sp-sn m hrt-ntr n</i> <i>"W3h-ib- R"</i> Translation Justified by Osiris, the great god, ruler of eternity, May he offer (?) the wine twice in the necropolis to "Wahebre".
	Transliteration <i>Im3h hr Wsir ntr-ꜥ3 Wnn-nfr "W3h-ib- R" n [.....] psm?</i> Translation Justified by Osiris, the great god "Wennefer" (Onnophris) "Wahebre" in [.....]?
	Transliteration <i>hꜥp di nsw n Wsir 3w-ib hnty-imnt ntr-ꜥ3 nb smyt, di ꜥ hr ntrw[....] (n)</i> <i>"W3h-ib -R"</i> Translation An offering, which the king gives to Osiris the joyful, foremost of the west, the great god, lord of the necropolis, May hand be given among the gods to("Wahebre".

Figure 5. Technical images and transcriptions. Anterior side: (a) = UVL and (b) = its transcription. Right-lateral side: (c) = UVL and (d) = its transcription. Left-lateral side: (e) = IRR and (f) its transcription².

² Transcriptions, transliterations and translations have been undertaken by Ms. Mai Farah, Curator at the Documentation and Registration Department at the Grand Egyptian Museum

4.2 Identification of Wood Species

Wood has been studied in three sections obtained in the principal anatomical directions, TS, TLS, and RLS. The micrographs through comparison with the descriptions available in wood anatomy textbooks, atlases, and databases allowed for the identification of wood species. The micrographs indicate that the obelisk was carved from Greek juniper, *Juniperus excelsa* (M. Bieb.). The TS micrographs (Figure 6) show the distinct growth ring boundaries. It shows that intercellular spaces are visible throughout the wood in the transverse section, mainly in earlywood. The latewood tracheids are thick-walled. The TLS micrographs (Figure 7) show rays exclusively uniseriate with a ray height of up to 7 and rarely 9 cells (see arrow). The RLS micrographs (Figure 8) show predominantly uniseriate pitting in radial walls of earlywood tracheids. It also shows axial parenchyma transverse and end walls nodular. Ray tracheids are absent. The end walls of ray parenchyma cells are distinctly pitted. Horizontal walls of ray parenchyma cells are smooth (unpitted). Cross-field pitting is cupressoid.

The number of pits per cross-field in earlywood ranges from 1 to 2.

Juniper is a large tree reaching up to 20 m. It has needle-like leaves as well as scale leaves in fully-grown trees. It is a durable tree and its timber can be polished well (Types of wood, 2002). A few attestations are available for its use in Ancient Egypt (Types of wood, 2002). However, it is believed that juniper berries were found in ancient Egyptian tombs from the Predynastic ages (Nicholson and Shaw, 2000). As recorded in a 1500 BC papyrus (during the New Kingdom), juniper had a medical use in curing tapeworm in ancient Egypt (Milliken and Bridgewater, 2001). As mentioned in Papyrus Anastasi I, it was brought to Egypt from the seaport of Byblos (Kilani, 2016), currently Jubayl, a city in Lebanon (Kilani, 2016), for its high quality (Barbieri-Low, 2021). Woods from juniper are resistant to microbial decay by nature (Unger et al., 2001; Blanchette, 2003), as it has an aromatic oil with a turpentine-like odor, which is sometimes used in ancient Egypt during the mummification process to anoint the corps (Groom, 2012), as identified in King Tutankhamun mummy (Riggs, 2014).

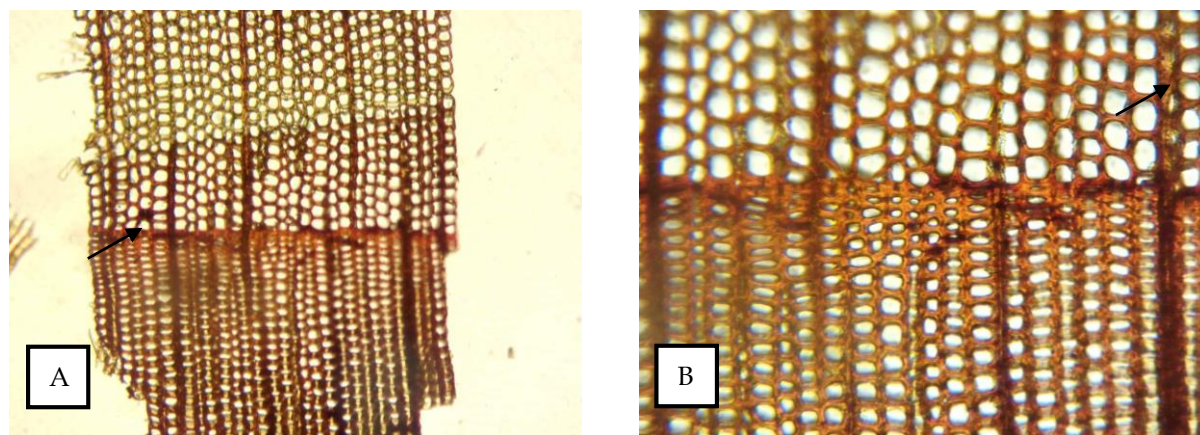


Figure 6. Micrographs of wood TS (A: 40x, B: 100x) of *Juniperus excelsa* used in the obelisk.

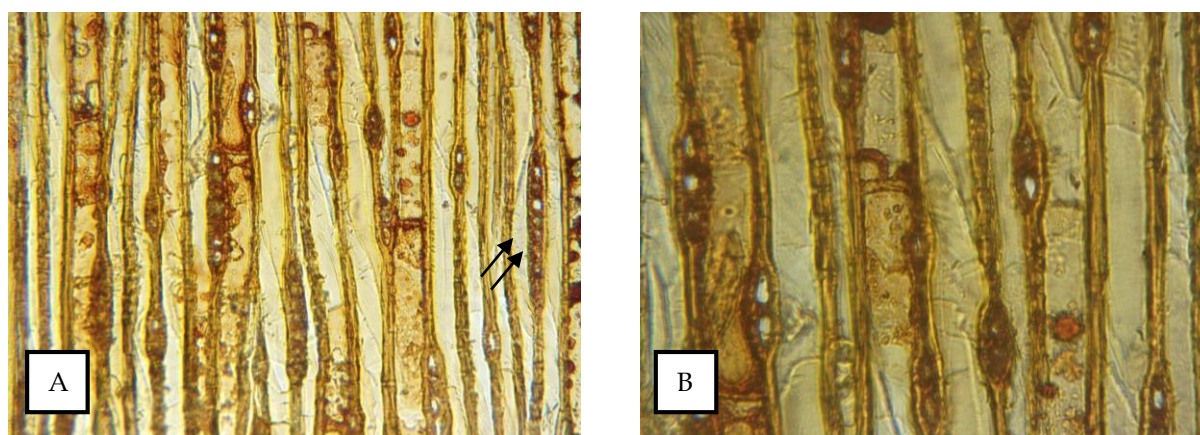


Figure 7. Micrographs of wood TLS (A: 40x; B: 100x) of *Juniperus excelsa* used in the obelisk.

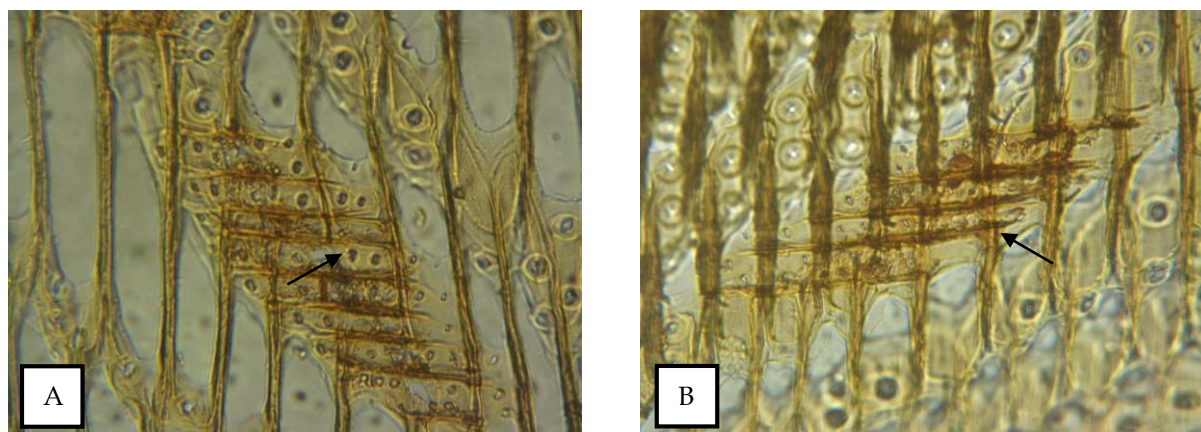


Figure 8. Micrographs of wood RLS (A: 100x; B: 200x) of *Juniperus excelsa* used in the obelisk.

As conifers are almost none porous and contain low starch, they are hardly susceptible to insect attack (Pournou, 2020). Therefore, it is supposed that the obelisk was long kept in an intensively attacked storage that caused its infestation although this type of wood is not very preferable to the insect itself.

Understanding that the wooden substrate to be treated is almost non-porous is particularly important and highly guides the level of penetration of the solutions to be used for stabilization.

4.3 Identification of Pigments

The responses of pigments to TI were dependent on the spectrum. In the VIS images, pigments were assigned to one of the following color categories: white, black, and blue. In the UVL images, the pigments were assigned to one of three categories: none

(meaning no sizeable fluorescence was observed), white or medium purple and black. In the UVR images, pigments were defined as UVR bright or dark. In the VIL images, Egyptian blue pigment showed up as bright white areas against a dark background, while others showed no luminance. In the IR images, pigments showed two simple responses: bright, dark. The VIS images were copied and edited to become the IRFC images as described by Cosentino (2015). In the IRFC images, pigments were assigned to one of the produced colors: red, black, and white.

Based on the obtained results, the unique obelisk contains three main pigments: white, blue, and black. The TI and XRF results are summarized in Table 2 and the elemental concentration in each pigment is summarized in Table 3.

Table 2. The examined object; its colors, composition, and technical imaging color results.

Color	Technical Imaging Color Results						XRF Results	Overall Result
	VIS	UVL	UVR	VIL	IR	IRFC		
White	White	White to Medium Purple	Bright	None	Bright	White	Ca, Si, S, Cl, Ar, Ti, Mn	Gypsum
Blue	Blue	None	Dark	Bright	Dark	Red	Ca, Fe, Cu, Cl, As, Si, S, K, Ti, Ni	Egyptian Blue
Black	Black	Black	Black	Black	Black	Black	Ca, P, Fe, Cl, Si, Cu, S, Ti	Bone Ivory

Table 3. Results of XRF analysis: number and type of samples with their resultant elemental composition ratios.

Sample			Elemental Composition (%)										
No	Material	Sr	Cu	Ni	Fe	Fe	Ca	K	Si	Cl	S	Mg	P
272	White	0.002	0.778	0.005	0.015	0.007	2.026	0.173	1.67	0.641	0.561	0.263	0.128
269	Blue	0.002	0.204	0.004	0.009	0.009	0.955	0.125	2.902	0.582	0.606	0.182	0.114
271	Black	0.002	0.324	0.004	0.018	0.006	1.696	0.124	1.594	0.868	0.7	0.266	0.164

4.3.1 White Pigment

White pigmented areas in VIS technical images appeared bright in the UVR and IR technical images and white-to-medium- purple in the UVL technical image (Figure 9). DM images also showed the same results in the VIS, IR, and UVL images (Figure 10) indicating the presence of gypsum. XRF spectrogram of sample no. 272 showed Ca at 3.69 ($K_{\alpha1,2}$) and 4.01 (K_{β}) as the predominant element. Cl also appeared in a high concentration at 2.62 ($K_{\alpha1}$) probably as a result of weathering (Elkhial, 2019). Si appeared at 1.74 ($K_{\alpha1,2}$), S at 2.31 ($K_{\alpha1,2}$) and Sr at 14.10 ($K_{\alpha1}$), 14.16 ($K_{\alpha2}$) and 16.09

($K_{\beta2}$) confirming the presence of gypsum. In conclusion, the TI results together with the XRF results confirm that the white pigment is calcium sulfate, gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).

Calcium sulfate was used in ancient Egypt in different states of hydration: anhydrous (CaSO_4), and hydrated or gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Gypsum can be found in the Mediterranean and the Red Sea coasts and in oases of the Western desert in Egypt (Abdel-Ghani, 2009), and its use in ancient Egyptian wooden artifacts is documented in the literature (El Hadidi and Hamed, 2017). As a pigment, gypsum is considered stable in modified atmospheres; as it is not affected by any inert gas (Elkhial, 2019).

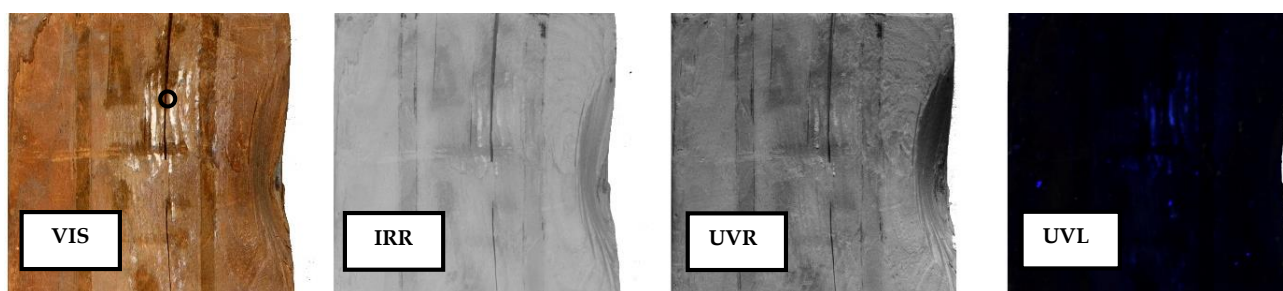


Figure 9. TI of white pigment showing it bright in the UVR image and medium purple in the UVL image. The black circle in the VIS image indicates the location of the XRF spot in 11.



Figure 10. DM micrographs (37x) of white pigment showing it bright in the IR image and medium purple in the UV image.

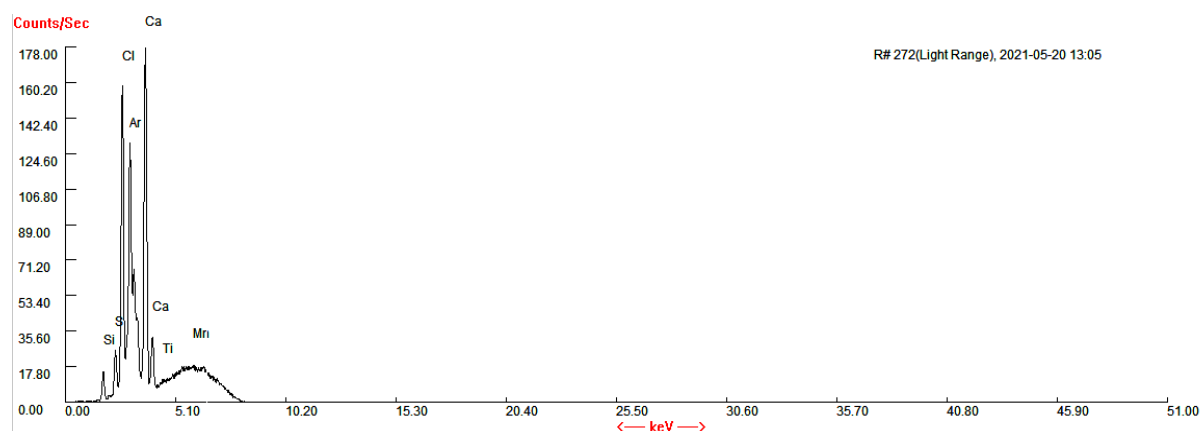


Figure 11. XRF spectrogram of the white pigment (sample no. 272 indicated with a circle in Figure 9).

4.3.2 Blue Pigment

Blue pigmented areas appeared dark in the IR images (Figure 12) and showed a highly notable visible luminance on a completely dark background in the VIL images (Figure 13) confirming the presence of Egyptian blue (Elkhial, 2019; Abdelmoniem, et al., 2020). The luminance was mainly detected in the line bordering the inscriptions between the two black lines. The XRF spectrogram showed Cu at 8.03, 8.05 ($K_{\alpha1,2}$), and 8.91 ($K_{\beta1}$) as the predominant element. Additionally, Ca appeared at 3.69 (K_{α}) and 4.01 (K_{β}), Fe at 6.40 (K_{α}), and 7.06 (K_{β}), Cl at 2.62 (K_{α}) and 2.81 (K_{β}), Si at 1.74 ($K_{\alpha1,2}$), and S at 2.31 ($K_{\alpha1,2}$). These results confirm that the pigment responsible for the blue color is Egyptian blue (Fitzgerald, 2008; Larsen et al., 2016; Elkhial, 2019). Cl lines may attribute the presence of

copper chlorides, as deterioration products of Egyptian blue (Abdel-Ghani, 2009).

Egyptian blue is calcium copper tetra silicate ($\text{CaCuSi}_4\text{O}_{10}$) (Mahmoud, 2011). It was the first synthetic pigment that has been used since antiquity and until the 7th century AD (Calza et al., 2007; Abdel-Ghani, 2009; Elkhial, 2019) by mixing sand and a calcium salt with copper compounds, and the product is mixed with the medium prior to painting the surface (Barnett et al., 2006).

Egyptian blue is generally stable in modified atmospheres at laboratory conditions. As inferred by Elkhial (2019), Egyptian blue in animal glue medium might slightly undergo color change when treated with carbon dioxide-induced modified atmosphere (65% CO_2) at high RH level (80-85% RH). It is consequently recommended to avoid high RH, CO_2 rich modified atmosphere treatments.

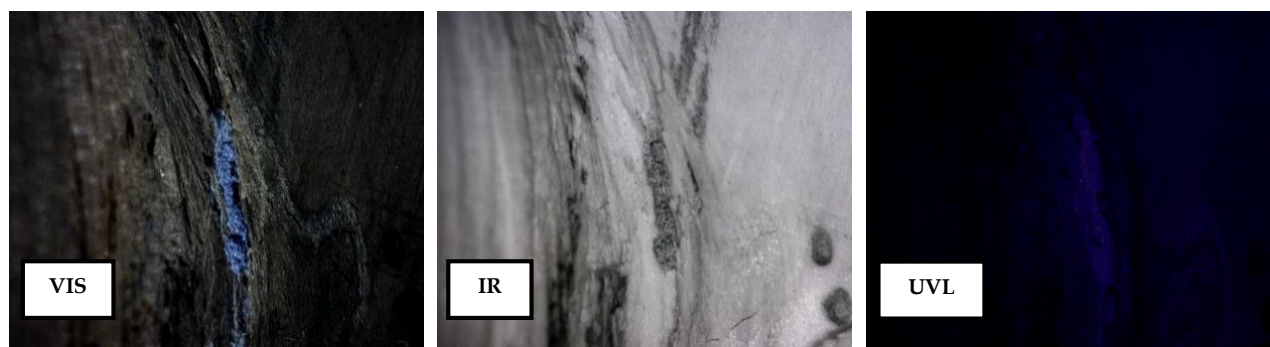


Figure 12. DM micrographs (30x) of a line of blue pigment showing it dark in both the IR and UV image.

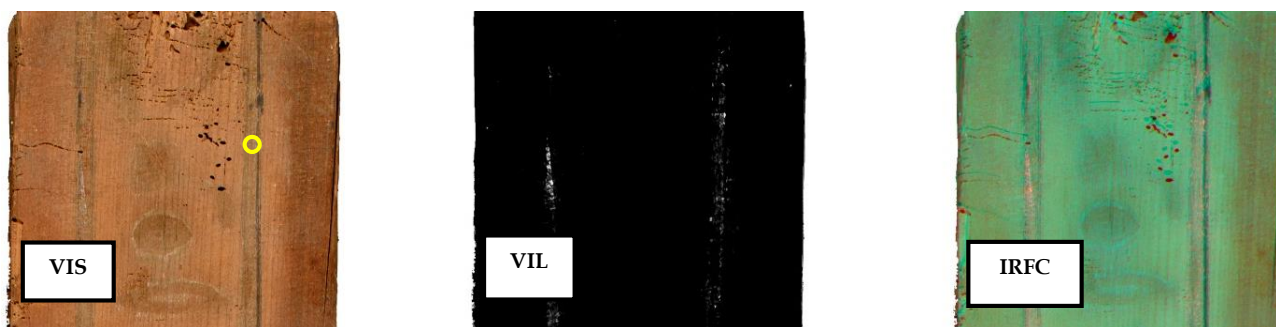


Figure 13. TI of areas containing traces of blue pigment showing it bright in the VIL image and reddish in the IRFC image. The yellow circle in the VIS image indicates the location of the XRF spot graphed in 14.

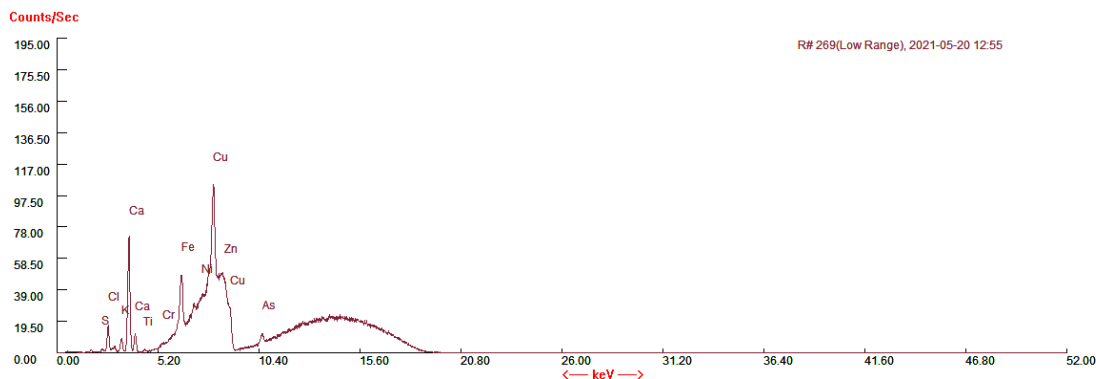


Figure 14. XRF spectrogram of the blue pigment (sample no. 269 indicated with a yellow circle in Figure 13).

4.3.3 Black Pigment

Examination using DM revealed that areas covered with black pigment appeared black in visible, IR, and UV light (Figure 15). They also appeared black in all TI images indicating the presence of a carbon-based black pigment (Figure 16). It is worth noting that carbon black pigments aren't distinguishable using TI, but can only be distinguished from iron-based black

ink (Cosentino, 2014). The XRF spectrogram of sample no. 271 (Fig. 17) revealed the appearance of Cl in a high concentration at 2.62 ($K_{\alpha 1}$) and Ca at 3.69 ($K_{\alpha 1,2}$) and 4.01 (K_{β}) as the predominant element. Si line also appeared at 1.74 ($K_{\alpha 1,2}$), P at 2.01 ($K_{\alpha 1,2}$), 2.14 ($K_{\beta 1}$), and Fe at 6.40 ($K_{\alpha 1,2}$). The presence of Ca along with P lines attribute that the black pigment is probably bone ivory. Carbon black is proved to be stable in modified atmospheres; as it is not affected by any inert gas (Elkhial, 2019).

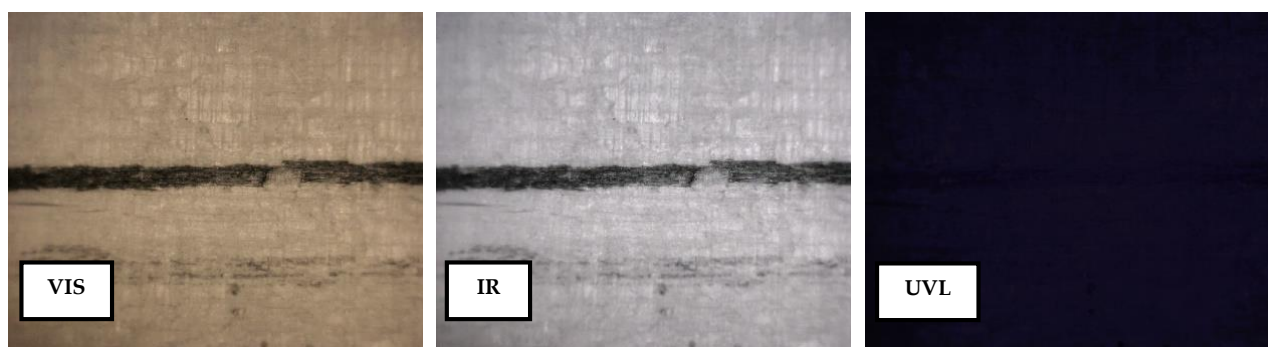


Figure 15. DM micrographs (40x) of a line of black pigment showing it dark in both the IR and UVL images.

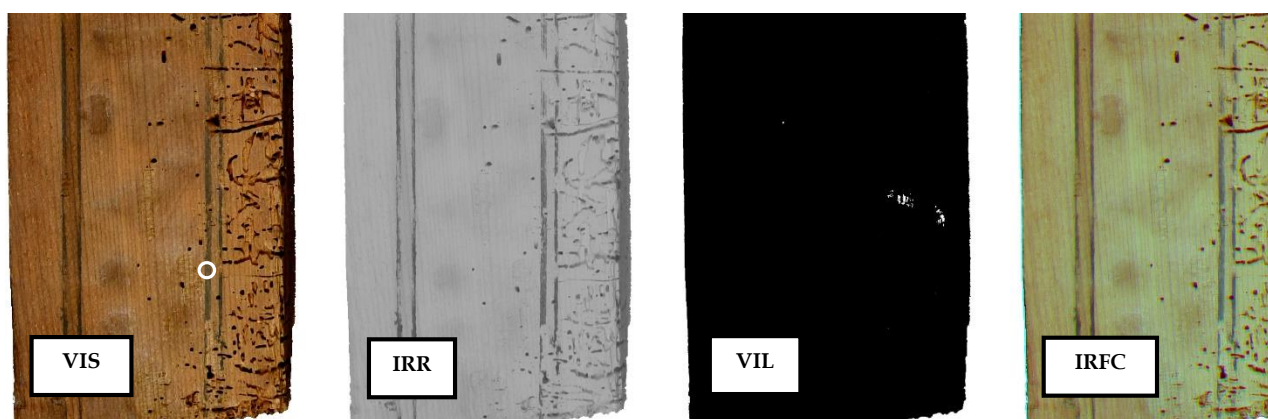


Figure 16. TI images of black pigmented lines showing them dark in the IR image and black in the VIL image and IRFC image. The white circle in the VIS image indicates the location of the XRF spot no. 271 graphed in 17.

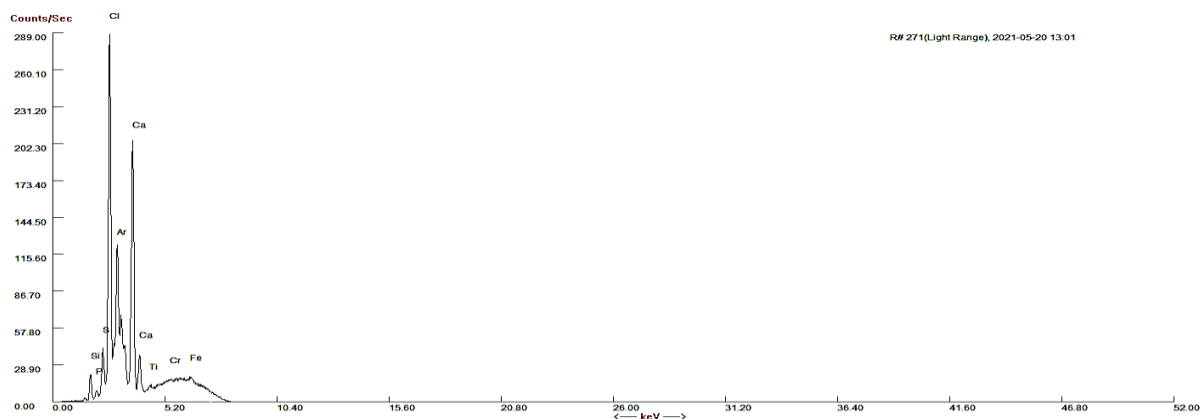


Figure 17. XRF spectrogram of black pigment (sample no. 271 indicated with a white circle in Figure 16).

Carbon black is the most used black pigment throughout the ancient Egyptian periods (Abdelaal *et al.*, 2014). It is made from the partial burning of a variety of materials, such as wood, oil, bone, or other organic materials. Bone black is made of calcium compounds, mainly phosphate and carbonate, in addition to organic collagen and lipids forming the coarse grain pigment (Abdel-Ghani, 2009).

5. CONCLUSION

This study focused on the multi-instrumental examination of a unique ancient Egyptian wooden obelisk that has been transported to the Conservation Center of Grand Egyptian Museum (GEM-CC) from Cairo-Egyptian Museum, to be conserved and prepared for storage at the GEM. The obelisk is the only wooden example of this type of artifacts in this size at the GEM. Visual examination revealed that the obelisk is carved from one block of wood, and the base is missing and had been replaced by a new one. It also revealed that the obelisk is heavily invaded by insect pests. DM revealed that the wood used to make the obelisk is Greek juniper wood, a coniferous tree,

which adds to its value being one of the few objects made of juniper wood. As conifers are hardly susceptible to insect attack, it is supposed that the obelisk under study was kept in an intensively attacked storage, which guides the integrated pest management professionals at the GEM when receiving more objects from the same storage. Visual examination revealed the presence of trace pigments of white, blue and black color. Examinations by DM, TI, and XRF revealed that the obelisk has traces of white pigment identified as gypsum, blue pigment identified as Egyptian blue, and black pigment (bone ivory). The identification of wood gives an idea about its permeability to fumigation gases as well as to stabilization solutions. Moreover, the identification of pigment traces guides the choice of the most suitable inert fumigant for pest eradication and the basic perception for the conservation interventions to stabilize the obelisk's state-of-conservation. TI revealed the text carved on the obelisk, which was transcribed, transliterated and translated by JSesh software. Text translations revealed that the obelisk was used as an offering and it was owned by *Wahebre*.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, data curation, investigation, formal analysis, discussions and writing-original draft preparation, M.E.; validation, supervision, N.E.; writing-review and editing, M.E. and N.E. All authors have read and approved the published version of the manuscript.

ACKNOWLEDGEMENTS

The authors cordially thank Editor-in-Chief (Founder) of Scientific Culture Journal, Prof. Ioannis Liritzis, for his sincere collaboration and the anonymous reviewers for their constructive comments. The authors are very grateful to the Grand Egyptian Museum for their generous providing of investigation techniques, with sincere gratitude and deep appreciation to Dr. Hussein M. Kamal, General Director of the Conservation Center at the Grand Egyptian Museum for providing his heartfelt support, sincere and constant encouragement, and valuable suggestions to this research. We are also grateful to Mrs. Mai Farah, Curator at the Documentation and Registration Department at the Grand Egyptian Museum, who performed the transcription, transliteration, and translation of the inscriptions on the object in this study, from which this work has greatly benefited.

REFERENCES

- Abdallah, M., Abdrabou, A., and Kamal, H. M. (2020). Multiscientific analytical approach of polychrome Greco-Roman palette applied on a wooden model naos: case study. *Mediterranean Archaeology and Archaeometry*, 20(2), pp.45-65. DOI: 10.5281/zenodo.3746942
- Abdelaal, S., Mahmoud, N., and Detalle, V. (2014). A technical examination and the identification of the wood, pigments, grounds and binder of an ancient Egyptian sarcophagus. *International Journal of Conservation Science (IJCS)*, 5(2), 177-188.
- Abdel-Ghani, M. H. (2009). *A Multi-instrument Investigation of Pigments, Binders and Varnishes from Egyptian Paintings (AD 1300-1900): Molecular and Elemental Analysis Using Raman, GC-MS and SEM-EDX Techniques (Doctoral Dissertation)*. Bradford, England: Department of Archaeological Sciences, University of Bradford.
- Abdelmoniem M. A., Mahmoud, N., Mohamed, W. S., Ewais, A. Y., and Abdrabou, A. (2020). Archaeometric study of a polychrome wooden coffin from 26th dynasty-Egypt. *Mediterranean Archaeology and Archaeometry*, 20(1), pp.7-17. DOI: 10.5281/zenodo.3364825

- Al Khasawneh, S. and Elserogy, A. (2019). Conservation and restoration of church icon from Baptism Museum, Jordan: case study. *Mediterranean Archaeology and Archaeometry*, 19(1), pp. 85-91. DOI: 10.5281/zenodo.2585977
- Baker, R. F., and Baker, C. (2001). *Ancient Egyptians: People of the pyramids*. NY, U.S.A.: Oxford University Press.
- Barbieri-Low, A. J. (2021). *Ancient Egypt and Early China: State, Society, and Culture*. University of Washington Press.
- Barnett, J. R., Miller, S., and Pearce, E. (2006). Colour and art: a brief history of pigments. *Optics and Laser Technology*, 38, pp. 445-453.
- Blanchette, R. A. (2003). Deterioration in Historic and Archaeological Woods from Terrestrial Sites. (R. K. Koestler, Ed.) *Art, Biology, and Conservation: Biodeterioration of Works of Art*, pp. 328-347.
- Budge, E. A. (2003). *Cleopatra's Needles and Other Egyptian Obelisks* 1926. London: Kessinger Publishing.
- Calza, C., Anjos, M. J., de Souza, S. M., Junior, A. B., and Lopes, R. T. (2007). X-Ray microfluorescence analysis of pigments in decorative paintings from sarcophagus cartonnage of an Egyptian mummy. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 263(1), 249-252.
- Collier, M. and Manley, B. (2003). *How to Read Egyptian Hieroglyphs*. London, England: University of California Press.
- Cooper, W. R. (1877). *A Short History of the Egyptian Obelisks*. London: Samuel Bagster and Sons.
- Cosentino, A. (2014). Identification of pigments by multispectral imaging; a flowchart method. *Heritage Science*, 2, pp.1-12. doi:10.1186/2050-7445-2-8
- Curran, B. A. (2009). *Obelisk: A History*. Cambridge: MIT Press, Burndy Library (Cambridge, Mass..
- Curran, B. A. (2014). Obelisks in ancient Egypt. In S. H. (Ed.), *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*, Springer, Dordrecht, pp. 13-18. DOI:https://doi.org/10.1007/978-94-007-3934-5_8815-2
- Delaney, J. K., Walmsley, E., Berrie, B. H., and Fletcher, C. F. (2005). Multispectral imaging of paintings in the infrared to detect and map blue pigments. In M. D. Sackler (Ed.), *Scientific Examination of Art: Modern Techniques in Conservation and Analysis*, Washington, D.C.: The National Academies Press, pp. 120-136.
- Easton, R. L., Knox, K. T., and Christens-Barry, W. A. (2003). Multispectral Imaging of the Archimedes Palimpsest. 32nd *Applied Image Pattern Recognition Workshop* (pp. 111-118). Washington, D.C., USA: International Electrical and Electronics Engineers (IEEE). doi:10.1109/AIPR.2003.1284258
- El Hadidi, N. M., and Hamed, S. A. (2017). The effect of preparation layers on the anatomical structure and chemical composition of native Egyptian wood. *the First Vatican Conference*, Vatican, Italy, pp. 199-210.
- Elkhial, M. M. (2019). *Study on Some Operational Problems of Modified Inert Atmosphere Fumigation and their Solutions - Applied on a Selected Wooden Artifact (Master Thesis)*. Cairo, Cairo, Egypt: Faculty of Archaeology, Cairo University.
- Elkhial, M. M., and Kamal, H. M. (2018). A new approach for detecting the active insect infestation in museum objects using non-dispersive infrared spectroscopy. *Studies in Conservation*, 63 (sup.1), pp. 345-347. https://doi.org/10.1080/00393630.2018.1504452
- Fitzgerald, S. (2008). Non-destructive micro-analysis of art and archaeological objects using micro-XRF. *Archeometriai Műhely*, 3, 75- 80.
- Groom, N. (2012). *The Perfume Handbook*. Hong Kong: Springer Science & Business Medi.
- Ida, H. (2005). *X-Ray Fluorescence Analysis with Portable Instruments (Doctoral Dissertation)*. Kyoto University, Japan: Department of Materials Science and Engineering, Kyoto University, Japan .
- Iglesias-Franjo, E. and Vilares, V. (2016). Searching Four-Millenia-Old Digitized Documents: A Text Retrieval System for Egyptologists. *Proceedings of the 10th SIGHUM Workshop on Language Technology for Cultural Heritage, Social Sciences, and Humanities (LaTeCH)* (pp. 22-31). Association for Computational Linguistics. doi:10.18653/v1/W16-2103
- Khan, Z., Shafait, F., and Mian, A. (2013). Hyperspectral imaging for ink mismatch detection. *The 12th International Conference on Document Analysis and Recognition* (pp. 877-881). Washington, DC, USA: International Electrical and Electronic Engineers (IEEE). doi:10.1109/ICDAR.2013.179
- Kilani, M. (2016). A new tree name in Egyptian: r-b-r-n = "juniper" in the Tale of Wenamun. *Journal of Near Eastern Studies*, 75(1), 43- 52. doi:10.1086/684970
- Larsen, R., Coluzzi, N., and Cosentino, A. (2016). Free XRF spectroscopy database of pigments checker. *International Journal of Conservation Science (IJCS)*, 7(3), 659-668.

- Lettner, M., Diemy, M., Sablatnig, R., and Miklasz, H. (2008). Registration and enhancing of multispectral manuscript images. *18th European Signal Processing Conference (EUSIPCO 2008)*, pp. 1-5. Lausanne, Switzerland: International Electrical and Electronics Engineers (IEEE). doi:10.5281/zenodo.41086
- Mahmoud, H. H. (2011). A preliminary investigation of ancient pigments from the mortuary temple of Seti I, El-Qurna (Luxor, Egypt). *Mediterranean Archaeology and Archaeometry*, 11(1), pp.99-106.
- Milliken, W., and Bridgewater, S. (2001). *Flora Celtica: Sustainable Development of Scottish Plants*. Edinburgh: Birlinn General.
- Nicholson, P. T., and Shaw, I. (. (2000). *Ancient Egyptian Materials and Technology*. Cambridge University Press.
- Obelisks in ancient Egypt*. (2003). Retrieved July 22, 2021, from Digital Egypt for Universities: <https://www.ucl.ac.uk/museums-static/digitalegypt/architecture/obelisks.html>
- Polis, S. and Winand, J. (Eds.). (2013). *Texts, Languages & Information Technology in Egyptology: Selected Papers from the Meeting of the Computer Working Group of the International Association of Egyptologists (Informatique & Égyptologie)*, Liège, 6-8 July 2010. Presses universitaires de Liège.
- Riggs, C. (2014). *Unwrapping Ancient Egypt* (1st ed.). Bloomsbury Publishing, ISBN: 9780857856777.
- Rosmorduc, S. (2014). JSesh Documentation. Retrieved August 20, 2021, from <http://jseshdoc.qenherkhopeshef.org>
- Sorek, S. (2010). *The Emperors' Needles: Egyptian Obelisks and Rome* (1st ed.). Liverpool University Press.
- Tassie, G. J., De Trafford, A., and van Wetering, J. (2015). Egypt's heritage in times of conflict and crisis. In F. A. Hassan, G. J. Tassie, L. S. Owens, A. De Trafford, J. van Wetering, and O. (. El Daly, *The Management of Egypt's Cultural Heritage*, Vol. 2, pp. 14-47. London: ECHO and Golden House Publications.
- West, G. (2019). *The Tekenu and Ancient Egyptian Funerary Ritual*. Archaeopress Egyptology 23, Glennise West and Archaeopress.
- Types of wood*. (2002). Retrieved July 18, 2020, from Digital Egypt for Universities: <https://www.ucl.ac.uk/museums-static/digitalegypt/wood/types.html>