The Application of Reflectance Transformation Imaging (RTI) and Multispectral Imaging (MSI) on the coffin-lid of Djedmut, Chantress of Amun-Re (Inv. IMJ 82.2.341) at the Israel Museum, Jerusalem: New analytical approach to workshops identification

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Abstract

This paper will focus on the coffin-lid of Djedmut, Chantress of Amun-R (Inv. IMJ 82.2.341), donated to the Israel Museum in the early 1980s and dating from the late Twenty-first Dynasty to the early part of the Twenty-second Dynasty. In the present research, Reflectance Transformation Imaging (RTI) is combined with Multispectral Imaging (MSI), valuable for the study of the pigments, to improve a detailed analysis and visualization of the artifacts' surface and highlight otherwise difficult-to-perceive features. This analysis enhances faded decorations, reveals underdrawings, and aids in the identification of pigments, binders, modifications, and other minute details of the production process, thus contributing to the identification of specific workshop profiles.

Keywords: Multispectral Imaging (MSI), Reflectance Transformation Imaging (RTI), Coffins, Third Intermediate Period, Pigments
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تتناول الدراسة غطاء تابوت ديدموت Djedmut، مغنية آمون رع (رقم حفظ IMJ 82.2.341)، والذي أُهدي إلى متحف إسرائيل في أوائل ثمانينات القرن الماضي، ويعود تاريخه إلى نهاية الأسرة الحادية والعشرين وبداية الأسرة الثانية والعشرين. واستخدمت تقنية التصوير بتحويل الانعكاس Reflectance Transformation Imaging (RTI) والتصوير متعدد الأطياف Multispectral Imaging (MSI)، والتي ثبتت فعاليتها في دراسة الأصباغ، لتحسين التحليل التفصيلي لسطح الأثر وتصويره وإبراز السمات التي قد تصعب ملاحظتها بتقنيات أخرى. حسّنت هذه التقنية جودة الزخارف الباهتة، وكشفت عن الطبقة التحضيرية، وساهمت في التعرف على الأصباغ والمواد اللاصقة والتعديلات، بالإضافة إلى بعض التفاصيل الدقيقة الأخرى في عملية الإنتاج، مما ساعد في التعرف على خصائص ورش العمل.

الكلمات المفتاحية: التصوير متعدد الأطياف، تقنية التصوير بتحويل الانعكاس، التوابيت، عصر الانتقال الثالث، الأصباغ

1. Introduction

Polychrome decorated coffins, especially those from the first millennium BCE, are among the most important artifacts from Ancient Egypt. The detailed study of decorated coffins enables one to obtain information on the society of the time, individuals and their families, titles, and institutions. The identification of distinctive thematic and stylistic motifs on contemporaneous coffins (Van Walsem 1997) suggests the presence of specific workshops that catered to particular subgroups within Egyptian elites (Van Walsem 2017: 557-574). Therefore, recent research also aims to reconstruct the production techniques and the social

agency of the artists involved in the process. The present research aims to further characterize "workshop profiles" using Reflectance Transformation Imaging (RTI) and Multispectral Imaging (MSI) in order to define the painting techniques, the materials used, and the modus operandi of the ancient artists.

2. Third Intermediate Period Coffins and the Egyptian Coffin-lid of Djedmut at the Israel Museum

The discovery in the late 19th century of the caches at Deir-el-Bahari (TT 320) (Aston 2021) and at Bab el-Gasus (Cooney 2021), containing hundreds of coffins dated to the early Third Intermediate Period, began a great adventure in Egyptology. During the 20th century, the number of coffins increased greatly thanks to new discoveries, but it was not until the studies undertaken by K. Kitchen (Kitchen 1986) on the Third Intermediate Period (TIP) and Niwinski's typological research (Niwinski 1988) that they received the recognition they deserved. Initially, the coffins were studied with special attention to the epigraphic aspects and the funerary texts. The importance of material culture and its contribution only began to be considered after A. Niwinski's pioneering work on the Theban coffins of the Twenty-first Dynasty and J. Taylor's studies on the coffins of the Twenty-second to the Twenty-Sixth Dynasty (Taylor 1985). Further advancements were undertaken by K. Cooney, focusing on coffin reuse patterns as social responses to crisis, elaborating on the economic and political changes at the beginning of the Third Intermediate Period (Cooney 2017: 101-112). In recent years, a materiality-based approach encouraged the application of advanced analytic methods, such as spectroscopy and microscopy, aimed at identifying the artist's techniques and procedures, the materials, and the pigments employed (Abdrabou 2017: 51-63; Asensi Amoros 2017: 45-50). Different approaches were adopted by Egyptologists in studying the coffins, but the identification of different workshops remains a field in need of further exploration, due to the absence of a general comparative dataset of the various specimens spread over many museums, all over the world. The two anthropoid wooden coffin-lids today preserved at the Israel Museum were donated in the early 1980s by Wilma and Lawrence Tisch, purchasers of the Dayan collection. There are no records as to how these coffins reached Moshe Dayan (Ben-Dor Evian in press). One of these is the coffin-lid of Djedmut, chantress of Amun-Re (Inv. IMJ 82.2.341, Figure 1),

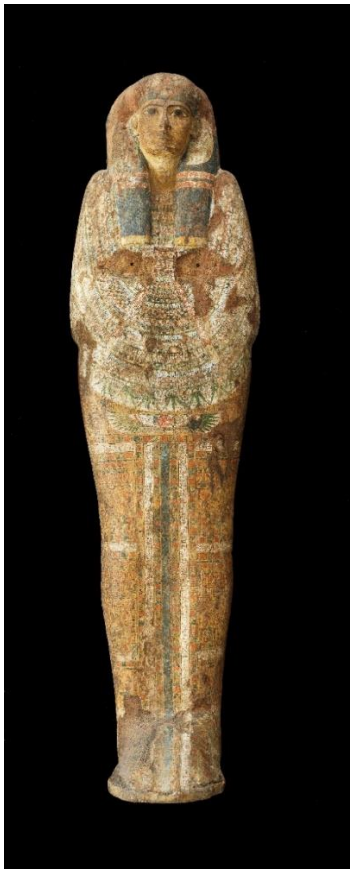

FIGURE 1: Coffin-lid of Djedmut, Inv. IMJ 82.2.341 (photo: © the Israel Museum, Eli Posener).

most likely originated from the Theban area[1]. It represents a female deceased and is coated with a yellow base and decorated in polychrome. The details are outlined in red and then filled with red, green, and blue pigments. The base of the feet and the inner lid were left undecorated. The iconographic characteristics and the coloring technique allow us to identify the coffin as Type V of the Yellow category, dating from the late Twenty-first Dynasty to the early part of the Twenty-Second Dynasty. The coffin-lid shows a blue tripartite wig with two lappets, and a colorful vulture headdress decorates the upper part. A wide floral collar begins beneath the wig and includes alternating rows of floral motifs and checkered designs. The last row consists of lotus flowers alternating with small diadems. The woman's hands are missing, and only two sockets are still visible. The two red stripes imitate the leather items of the mummy shrouds, and, just below the wig's lappets, a pectoral represents a solar bark in the upper scene and below a *djed* pillar flanked by two coiled cobras above *neb* signs, with the hieroglyphs for the goddess Wadjet. Under the collar, a winged solar disc flanked by two uraei is in the middle of two symmetrical scenes representing the mummified deceased with his offerings to two deities on a throne: Amun on the left side of the coffin-lid and an unidentified god on the right (the figure is not well preserved). A checkered frieze separates the lower part of the coffin-lid, which is divided vertically into three sections: three vignettes decorate the right and the left side, while in the middle, two columns of inscriptions alternate with geometric motifs. The vignettes are separate by geometric friezes: a line of inscriptions and a frieze of uraei crowned with solar discs. Every scene represents a different mummiform deity standing in front of a seated god holding the sceptres *heqa* and *neheh*. Vessels on stands as ritual offerings are located between them. In the two vignettes at the bottom, for reasons

[1] At the time of its arrival to the museum, no provenance documents were presented. Dr. Ben Dor Evian's personal inquiry led to a close acquaintance of Dayan who confirmed that the coffin was on display at Dayan's home for many years prior to his death. He remembered that it was purchased in London. Personal communication to Dr. Ben Dor Evian, August 24, 2017.

of space, the seated god is not on a throne, but he is squatting on a checkered basket. A fourth vignette, situated at the feet (the symmetrical one is not preserved), represents the winged Wadjet in front of a sistrum. The inscription is carelessly executed while the vignettes are more expertly painted. Perhaps two different hands worked on the coffin. The two central vertical columns of texts include a recitation by the god Re-Horakhty-Atum and other deities with their titles, while the horizontal inscriptions accompanying the vignettes are badly damaged and difficult to decipher even with the help of Multispectral Imaging. The texts are written on a white background, and the signs are in red filled with traces of blue and green pigments. On the contrary, the texts inside the vignettes have been inscribed with red ink on the yellow coating.

3. RTI and MSI Methodology

Reflectance Transformation Imaging (RTI) is a computational photographic technique invented by Tom Malzbender and Dan Gelb, researchers at Hewlett-Packard Labs. A landmark paper describing these first tools and methods was published in 2001 (Malzbender 2001: 519-528).

RTI captures the surface and color of an object and allows it to be interactively reilluminated from any direction; the enhancement functions of RTI reveal surface information that is not disclosed under direct empirical examination of the object (CHI 2002-2020)[2].

RTI has been applied in the study of the coffin-lid of Djedmut using a NIKON D850 camera with a 46MP sensor on which a SIGMA 50MM 2.8 mm macro lens has been mounted. The light was projected from a GODEX 200W flash.

This technique can be used on small or large objects (up to 2 m in diameter) and can be adapted to a larger choice of surfaces or places (stelae, tomb reliefs, rock art, etc.).

RTI is a non-invasive technique that eliminates all physical contact with the object. This enables us to analyse the texture of the surface and to record details that are very difficult to grasp with the naked eye or by conventional photography.

The other imaging technique we used in the analysis of the coffin-lid is the Multispectral Imaging (MSI) to analyse an object through selected ranges of wavelengths in the electromagnetic spectrum that include and extend beyond the capabilities of the human eye.

MSI measures the reflectance and fluorescence properties of various pigments using different wavelengths of light. The following analysis has been carried out on the coffin-lid with a Fujifilm X-T30 Multispectral (350-1100 nm) camera and a Fujinon XF 50 mm lens, combined with the application of different filters and radiation sources:

- Ultraviolet florescence (UVF) records the reflected radiation in the ultraviolet region (400-700 nm): the images are taken using the modified digital camera with Hoya filter UV & IR Cut and a UV 365 nm filtered source by Madatec.
- Ultraviolet Reflectography (UVR) highlights varnishes and helps us to identify white pigments made of different chemical compositions (365 nm); the images are taken

[2] https://culturalheritageimaging.org/ > (accessed 09.07.2024).

using a modified digital camera with a UV Band pass filter and a UV 365 nm filtered source by Madatec.

- Visible-induced luminescence (VIL) records the emission of radiation (luminescence) in the infrared region. These images characterize the spatial distribution of pigments such as Egyptian blue (of the same composition as the naturally occurring mineral cuprorivaite), Han blue, Han purple, and cadmium-based pigments. Egyptian blue shows a broad emission at 910 nm and requires the maximum reduction of infrared parasitic light. In this way, it is possible to obtain a resolved image of artifacts, even in traces. The images are taken using the above-mentioned modified digital camera, with a red-light source 640 nm by Madatec and an IR pass filter 850 nm.
- Infrared Reflectography (IRR) records the reflected radiation in the infrared region (700-1000 nm). The images are taken using the above-mentioned modified digital camera combined with an IR filter of 850 nm and manual flash.

3. RTI and MSI applied to the coffin-lid of Djedmut

The stratigraphic structure used in the preparation of Third Intermediate Period Egyptian coffins is composed of different layers. The wooden support is covered by mud (occasionally with the use of fabric) and then with beige and white preparation layers, usually made of clay plaster and calcium-gesso, on which the polychrome decoration is applied, and sometimes covered by varnish (Brunel-Duverger 2020: 12-13).

The coffin-lid of Djedmut is made from planks of different pieces of wood (mainly sycamore and tamarisk) joined together by dowels and tenons. The planks are covered with a coarse brown-grey layer. Two different types of mud layers can be observed by the naked eye: a lumpy dark layer with white inclusions above the ear (probably used to shape the wig) and a thinly applied clay layer under the blue pigment of the wig. No white layer is preserved or visible here under the pigments. The lumpy dark layer includes a mixture of clay and plant fibers, visible in some areas of the head and of the body of the coffin-lid.

RTI can provide additional information about the surface condition of the painted layers, highlighting grainy surfaces of the pigments, marks relating to surface preparation, and thin areas of texture, imperceptible to the naked eye or to other inspection techniques. In the field of Egyptology, it has only recently gained increased attention as a tool for the analysis of painted wooden surfaces (Buscaglia 2021: 531-550) and for clarifying fine surface details of tool marks, inscriptions, and other data on archaeological artifacts.

RTI imaging on the top of the coffin's head reveals chiselling marks that attest to the removal of some coating layers, indicating perhaps the original presence of precious materials, such as gilding. The only original part is the lower right corner, showing pigments on a light-colored preparation layer (Figure 2).

FIGURE 2: Chiselling marks on the back of Djedmut's head—Detail taken with RTI (photo: Shai Halevi and Daniela Galazzo).

RTI is also a tool to enhance the details of manufacturing and pigment application methods. It is a natural way to document painting, since it overcomes the limitations of requiring raking light photography to reveal the decoration lines and methods.

A case in point is Djedmut's floral collar, consisting of flowers, leaves, and geometrical motifs, painted as if they were draped in garlands over the chest, in a stylized manner with some three-dimensionality achieved using outlines, color contrasts, and glazes (Emmett 2022: 49-58). By applying the "Normals visualization" in RTI, it becomes evident that the Egyptian blue was applied as a "paste" in raised relief in the drops and the checkered motifs (Figures 3 a-b).

FIGURE 3 (a): Detail of the collar in visible light (photo: Shai Halevi and Daniela Galazzo).

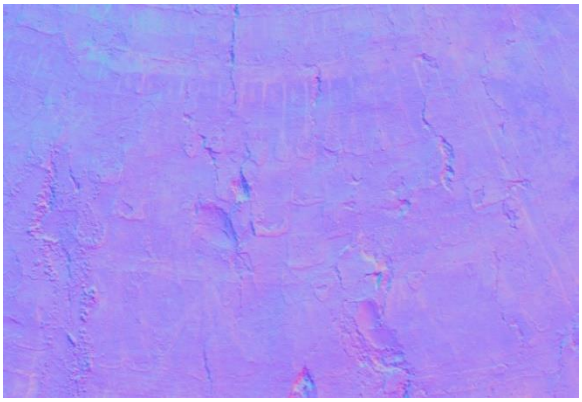

FIGURE 3 (b): Detail of the collar in visible light in RTI through the "Normals visualization" (photo: Shai Halevi and Daniela Galazzo).

Analysis of the binding medium on other coffins with similar pastes suggested the use of plant-based gum (Emmett 2022: 54). Plant fiber brushes were used to generate relief using several layers (Emmett 2022: 54). These collar areas have generally an extra white layer in stratigraphy, applied on the top of the white gypsum preparation layer, which is much brighter because of the possible use of huntite, a magnesium-calcium-

carbonate pigment[3].

Using MSI on coffin surfaces and changing between different filters, the sequence of the painting layers becomes clearer. This sequence begins with the application of preparation layers on the wood, followed by marking-out lines, applying background color, underdrawing, and filling-in of text and decoration with red, blue, and often green. The varnish is generally applied last on the coffin surface.

Another aspect that can be observed by RTI on this coffin-lid is the painter's brushstrokes. The brush is the archetypical painter's tool. Most of the brushes found in Egypt were made of plant fibers (Dawson 2016: 75-111). Broad brushstrokes can be visible because of the use of relatively coarse pigments and water-based binding medium. However, finer brushes have been used for the red, blue, and green sections of the polychrome decoration, as can be observed on the lotus flower petals of Djedmut's collar and on the winged sun disc just below (Figures 4 a-b).

FIGURE 4 (a): Detail of the winged sun disc in visible light (photos: Shai Halevi and Daniela Galazzo).

[3] The analysis of the materials used in the preparation of this coffin is in the process of publication.

FIGURE 4 (b): Detail of the winged sun disc RTI through the "Specular Enhancement" (photos: Shai Halevi and Daniela Galazzo).

These significantly successful applications demonstrate the great potential of RTI for analysing painted wooden surfaces and in particular for the identification of workshops and artisans' hands, a venue which has so far been only marginally explored through RTI.

The MSI imaging performed on Djedmut's coffin-lid included Infrared Reflectography (IRR), which is usually highly penetrative since many materials, such as organic binders and colorants, such as red ochre, are generally transparent to infrared wavelengths. This method is focused on the identification of underdrawings, *pentimenti,* and characterizations of the inks.

Infrared imaging allows us to visualize underdrawings when they are realized through carbon-based pigments and when they are not too far down in the stratigraphy. In the case of Djedmut's coffin-lid, the IRR enhances in the central panel the accurate organization of the space between the text and the vignettes, while the outlines for the vignettes representing the scenes of the Book of the Dead (Ben-Dor Evian 2025) are less defined, on both sides of the coffin-lid (Figures 5 a-b).

FIGURE 5 (a): Detail of the central panel in visible light (photos: Shai Halevi and Daniela Galazzo).

FIGURE 5 (b): Detail of the central panel through IRR imaging (photos: Shai Halevi and Daniela Galazzo).

The black pigment has not been chemically analyzed; however, it is probably black charcoal since it is very well detected by IRR imaging. The red pigment has been identified as ochre by Raman spectroscopy.

Visible-induced luminescence (VIL) is a very useful analytical tool for detecting and identifying Egyptian blue on the painted artifacts surface. In particular, this technique is important not only for the areas in blue but also for the green and black ones, in which Egyptian blue could be present in very small quantities, pure or mixed with other pigments. VIL imaging on Djedmut's coffin-lid reveals that many areas were painted with Egyptian blue, but others, appearing as green pigments to the naked eye, are bright under VIL filter. This means that either the green pigment included Egyptian blue particles in its composition, or the decoration was originally blue and the yellowing of a binding medium or a resin has changed its appearance[4]. A detail in VIL from the lotus frieze is very interesting, since it shows many more iconographic elements than it is possible to see in visible light: first of all, the thin petals painted in light/faint color appear very bright as they contain Egyptian blue, and also the drops alternating the lotus flowers appear well defined and bright (Figure 6).

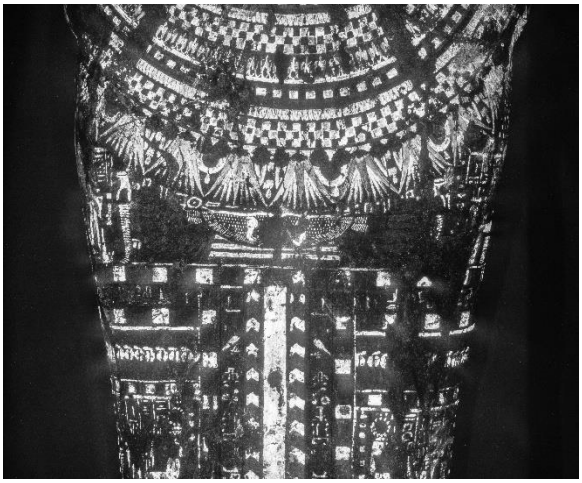

FIGURE 6: The floral collar in VIL (photo: Shai Halevi and Daniela Galazzo).

The pale blue color was usually obtained by grinding the synthetic cuprorivaite to a very fine powder.

[4] The analysis of the materials used in the preparation of this coffin is in the process of publication.

A very interesting feature outlined by VIL is the winged sun disc motif below the collar. This pattern appears in a great number of stola coffins, although with some iconographical differences. At naked eye, the area around the solar disc with the two uraei appears white, but thanks to the VIL, we can notice the presence of a great number of dots which have today almost completely disappeared, and they were probably outlined in black or blue (Figures 7 a-b).

FIGURE 7 (a): Detail of the winged sun disc in visible light (photos: Shai Halevi and Daniela Galazzo).

FIGURE 7 (b): Detail of the winged sun disc in VIL (photos: Shai Halevi and Daniela Galazzo).

In both cases, the pigment contained Egyptian blue, as well as the small strokes imitating the plumage of the bird. This motif is recurrent on a great number of coffins: an example is the coffin-lid of a woman preserved at the Wayne County Historical Museum in Richmond, Indiana (USA) (Sampsell 2020: 183-197), also originating from the Theban area, where these elements are in evidence. Another feature that this coffin-lid shares with Djedmut is the iconographic similarity of the collar (although without the pectoral), which defines a possible common Theban workshop for the upper part of the coffin's decoration. Moreover, the bottom part of the wings under the sun disc presents a striated motif. In visible light, a faint green strip alternates with a darker one, till the last strip in red, while the VIL makes the faint green brighten as much as the Egyptian blue (see Figures 7a-b). This motif is also attested on other coffins, such as the two stola coffins of Ankhefenkhonsu at the RMO in Leiden (AMM18-g)[5] and the one of Djedhoriuefankh at the Museo Gregoriano Egizio (Vatican Museums) (Gasse 1996: 44, pl. IV).

Ultraviolet fluorescence (UVF) imaging can be very useful in characterizing the superficial distribution of materials, such as varnishes, coatings, and differentiating retouching from original painting, as ultraviolet wavelengths are generally readily absorbed at the surface. It is very helpful in showing the evidence of modern interventions on Djedmut's coffin-lid: both sides of the artifact present yellowish areas, where modern material has been applied (Figure 8).

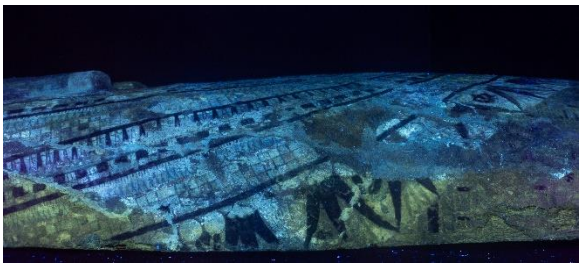

FIGURE 8: Detail of the right side of the coffin-lid in UVF imaging with modern interventions in yellow (photo: Shai Halevi and Daniela Galazzo).

Also, the use of Japanese conservation paper (documented as part of the conservation treatment at the Israel Museum) is evidenced by the fluorescence emitted.

[5] https://www.rmo.nl/en/collection/search-collection/collection-piece/?object=22130 (accessed October 2024)

Thanks to the contribution of UVF, it was possible to identify the head of one of the deities represented in the first vignette at the top, on the right side of the coffin-lid, very difficult to perceive: by naked eye, it is a mummiform standing deity outlined by red pigment and figured in front of a seated god crowned by a solar disc. The VIL allows us to identify the wig of the god originally in Egyptian blue, while through the UVF, we can observe his jackal face (Figures 9 a-c).

FIGURE 9 (a): Detail of the mummiform standing deity with jackal head in visible light (photos: Shai Halevi and Daniela Galazzo).

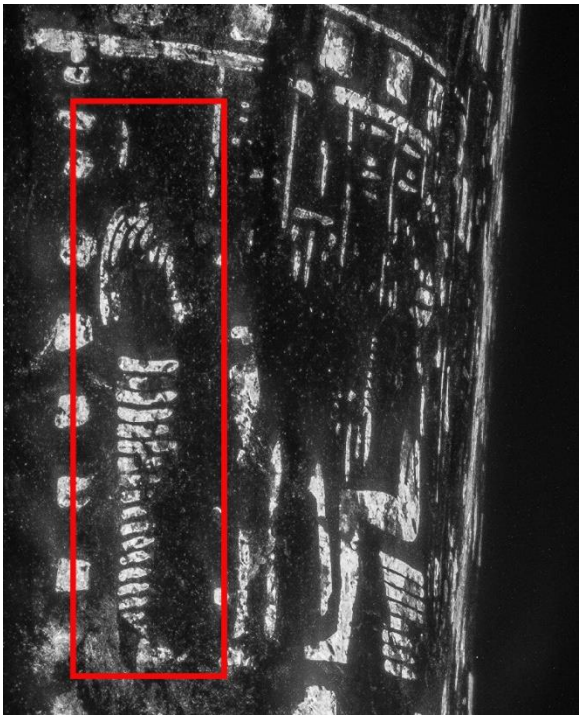

FIGURE 9 (b): Detail of the mummiform standing deity with jackal head in VIL (photos: Shai Halevi and Daniela Galazzo).

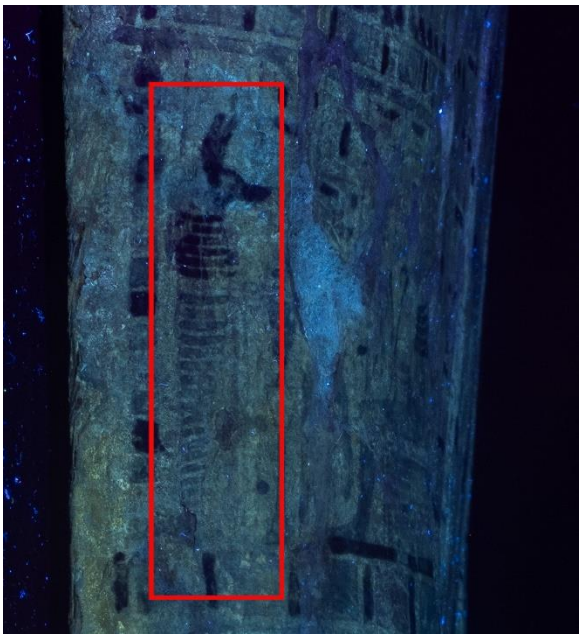

FIGURE 9 (b): Detail of the mummiform standing deity with jackal head in UVF (photos: Shai Halevi and Daniela Galazzo).

The original pigment used to paint the animal's face is a faint green. Although in

the absence of a scientific analysis of the pigment, we can affirm that the green indicates a copper-based pigment, known to quench the fluorescence of the surrounding media. However, the green pigments appear dark with the IRR because of the strong absorption properties of these in the near IR range (Moustafa 2022: 11). It is the same pigment also used as decorative filler for the hieroglyphs, the geometric patterns, and other figures in the vignettes. As L. Brunel-Duverger (et al.) demonstrated (Brunel-Duverger 2020: 16), the green pigments employed on the coffins during the Third Intermediate Period have been the product of the reuse of raw materials obtained by the transformation of bronze. The analysis on the coffins shows a wide variety of fabrication recipes being at the origin of each different shade of the color.

Conclusions

The new technologies, materials, and methodologies involved contribute to the establishment of a new field of research and, in particular, to the study of coffin workshops.

The technologies applied provide information on the identification of the artist's hand, the brush strokes, the artisans' tools, etc. The data can be used to explore the role of craftsmen and artists in Ancient Egypt and their influence on the artistic choices of the coffin owner.

The employed methodology not only illuminates hidden traits of the coffin production process but also explores new protocols for data retrieval through multispectral analysis and RTI to contribute to the conservation process of these heritage objects. The creation of digital images is also instrumental for the documentation, study, and conservation of the coffins.

The application of RTI provides new and valuable information about the surface condition of the painted layers, showing the surface of the pigments and provides also more details about the manufacturing techniques (marks relating to surface preparation that were imperceptible to the naked eye or by other inspection techniques). Finally, RTI enhances the morphology of some deteriorated materials, not easily visible but also parts treated by previous interventions as overpainting on the preparation layer. The imaging techniques applied have helped us to obtain different kinds of results and to improve the understanding and the readability of the decoration process of the examined coffin-lid.

Conflicts of Interests

The authors declare no conflict of interest.

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