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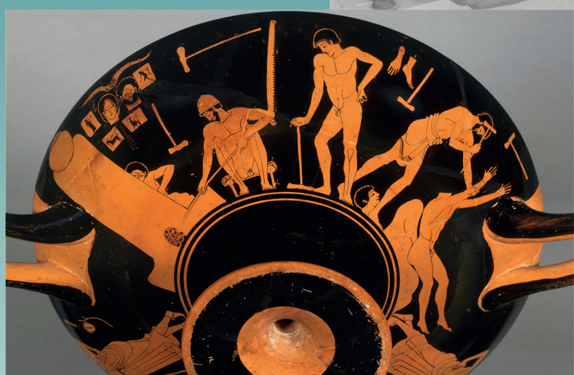

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Inhalt

Non-invasive micro-analytical study of five mummy portraits and the Severan Tondo of the Antiken-sammlung, Berlin

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Abstract

Five mummy portraits and the Severan Tondo from *Antikensammlung,* Berlin have been studied using non-invasive analytical methods including micro X-ray fluorescence analysis (µ-XRF) and microscopic diffuse reflectance spectroscopy (MDRS). A broad range of pigments was identified by the chosen analytical protocol: lead white, red lead, ochre, vermilion, and realgar. This result is consistent with other studies of mummy portraits. Differences in the paint palette have been observed as a function of the painting technique, encaustic or tempera. In encaustic paintings generally lead white was used whereas various white pigments were used in tempera paintings are more variable. Vermillion and orpiment had only been used infrequently.

1 Introduction

Mummy portraits are paintings of individuals which lived in Roman Egypt. The portraits had been used to decorate the mummified bodies for burial. This custom, genuine Egyptian, must have been costly and was only affordable for the upper class. In the 19th c. large numbers of these portraits were extracted from necropoleis in the Fayum area and were brought to Europe. An extensive collection of these items is housed at the *Antikensammlung* of the *Staatliche Museen zu Berlin*.

The Severan Tondo (Fig. 1) is a family portrait of the Roman emperor Septimius Severus with his family. It had been painted around 200 AD and is the only preserved painted portrait of a Roman emperor (Platz-Horster, 2016). The mummy portraits and tondo originate from Egypt and are from approximately the same period, but the tondo most probably was not from a burial context.

The mummy portraits of the *Antikensammlung* and the Severan Tondo have never been analytically studied before. Therefore, it was interesting to characterize the pigment palette of a selection of portraits from the Roman Empire.

The number of technical studies carried out in this type of objects is still limited. Some more recent publications are (Asensi Amorós *et al*., 2001; Cartwrigth and Middleton, 2008; Freccero, 2000; Wunderlich, 2000). Very recently a comprehensive study by Salvant and colleagues (2017) on a series of mummy portraits from the Tebtunis site in Egypt, 2nd c. has been published.

An on-going research project is the international APPEAR (for: Ancient Panel Paintings: Examination, Analysis and Research) collaboration between 26 museums with funerary portraits in their collections including the Getty Museum, the British Museum, the Penn Museum, the Phoebe Hearst Museum, the Ashmolean and the Museum of Fine Arts, Boston (Svoboda, n.d.).

A collaborative trans-disciplinary research project has been finalized recently: The ISIMAT project (Inkarnat und Signifikanz – Das menschliche Abbild in der Tafelmalerei von 200 bis 1250 im Mittelmeerraum) was financed by the Bundesministerium für Bildung und Forschung (BMBF) of the Federal Republic of Germany and coordinated by the Zentralinstitut für Kunstgeschichte, Munich Forschungsstelle Realienkunde (DLR, n.d.; Wipfler, n.d.). Partners in this project were the Lehrstuhl für Restaurierung, Kunsttechnologie und Konservierungswissenschaft, Technical University of Munich, the Doerner Institut, Bayerische Staatsgemäldesammlungen, Munich, and the Opificio delle Pietre Dure, Florence. This project ended in 2017 and generated a comprehensive publication (Schmuhl *et al*., 2017). In dedicated chapters within this publication the scientific results of the research were published including results on the objects discussed in this article (Dietemann *et al*., 2017; Sand, Fugmann, *et al*., 2017). The investigation of the objects from the *Antikensammlung* had been initiated by cooperation with colleagues from the ISIMAT Project.

Tab. 1: Reported pigments used on objects in Romano-Egyptian time

Red	Blue	White	Yellow	Green	Brown	Black	Pink
Ochre	Egyptian Blue	Lead white	Ochre	Green earth	Ochre	Cabon-based pig-ments	Combination of red ochre and white
Minium	Indigo (alum as substrate/ mordant)	Calcium sul-phates: Gypsum Bassanite	Jarosite	Egyptian green frit			Combination of madder and white
Vermillion		Calcite	Pararealgar	Malachite			
Realgar		Huntite	Orpigment	Coperbased green			
Madder		Alunite		Combination of Egyptian Blue and orpiment			
				Combination of Indi-go and orpiment			

Tab. 2: Objects and proposed painting technique

Ident. Nr.	Discription	Date and provenance	Size / mm²	Painting technique by visual characteristics	Image with measurements spots indicated
31161, 52	Mummy portrait of a woman	2nd century AD, Fayum, Egypt	335 x 94	Formerly documented as tempera, now as encaustic cf. (Sand, Thieme, and Rom-mel-Mayet, 2017, p. 190) severely damaged portrait	Fig. 2
31161, 27	Mummy portrait of a young woman	First third 2nd AD Fayum, Egypt	329 x 198	Encaustic	Fig. 3
31161, 12	Mummy portrait of a young woman	Mid-2nd century AD, Fayum, Egypt	395 x 110	Encaustic	Fig. 4
31329	Family portrait Septimi-us Severus, Tondo	End 2nd beginning 3rd centrury AD, Egypt	diameter 305	Tempera	Fig. 5
31161, 48	Mummy portrait of a young woman	First half 3rd century AD. Fayum, Egypt	402 x 214	Tempera	Fig. 6
31161, 49	Mummy portrait of a mature woman	First half 3rd AD Fayum, Egypt	310 x 146	Tempera	Fig. 7

The mummy portraits are generally painted on a rather thin sheet of wood panel of sycamore, oak, lime, pine or cedar wood. The thickness can vary from very thin sheet (1 to 3 mm) to up to more than one cm. The portraits are painted in different techniques which are differentiated by visual examination into three categories: tempera, encaustic and less frequently cold wax painting: (Sand, Thieme, and Dietemann, 2017).

Encaustic paintings are made with wax as binding material, which is coloured with pigments. The wax is at least partly applied and reworked by a heat treatment. The layers of paint are pastose with molten texture and silk matt appearance. Colour gradients of two neighbouring colours are achieved by the heating and reworking of the wax on the wood panel. Additionally, often brush marks which do not show signs of a heat treatment are visible on encaustic paintings. Paintings made with wax, but lacking the aspects of hot reworking of the applied wax, are called cold wax paintings. However, not all details of the cold wax painting are understood, and it is uncertain whether the coloured wax was applied without any heat treatment.

Tempera technique was well known in ancient Egypt. Commonly a gesso layer made of gypsum and glue was used to prepare the wood for painting (Freccero, 2000, p. 7).

Fig. 1: Portrait of Septimius Severus and his family, tondo from Egypt, inv. no. 31329.

Fig. 2: Portrait of a woman, Fayum (Egypt), inv. no. 31161,52; in red: spots of µ-XRF, in green MDRS analysis

Fig. 3: Portrait of a young woman, Fayum (Egypt), inv. no. 31161,27; in red: spots of µ-XRF, in green MDRS analysis

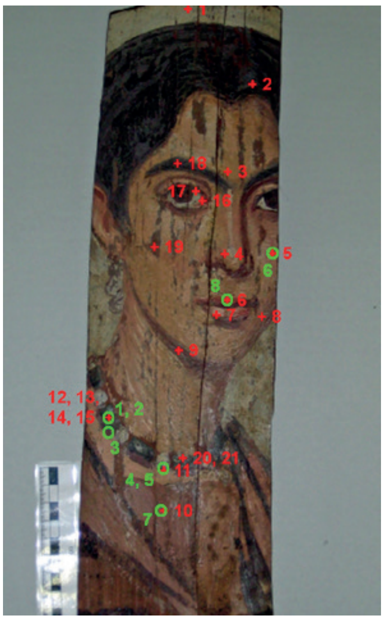


Fig. 4: Portrait of a young woman, Fayum (Egypt), inv. no. 31161,12; in red: spots of µ-XRF, in green MDRS analysis

Fig. 5: Detail of fig. 1, inv. no. 31329; in red: spots of µ-XRF, in green MDRS

Fig. 6: Portrait of a young woman, Fayum (Egypt), inv. no. 31161,48; in red: spots of μ-XRF, in green MDRS analysis

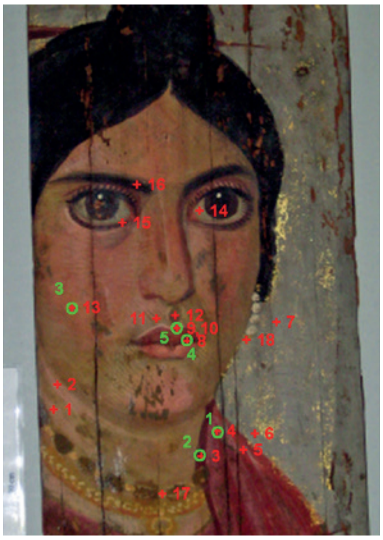


Fig. 7: Portrait of a mature woman, Fayum (Egypt), Inv.Nr.: 31161, 49; in red: spots of μ-XRF, in green MDRS analysis

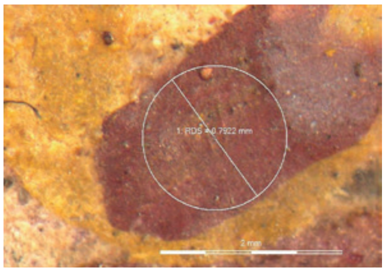


Fig. 8: Areas from the view field of the zoom microscope selected for MDRS investigation; 2x zoom. (31161,27 Pos. 2, Fig. 15)

The individual layers of paint are thin; the appearance of the paints is matt. Individual applications of paint can be recognized by the uniform colour. Shades of colours are often obtained by several overlaying brush strokes, transitions between colours by hatching (Sand, Thieme, and Dietemann, 2017).

The pigments used in Romano-Egyptian mummy portraits have been discussed in earlier works (Corcoran *et al*., 2010, p. 46; Dietemann *et al*., 2017, p. 203; Salvant *et al*., 2017). The results are summarized in Tab. 1. Among the white pigments also huntite is listed. The use of this mineral as a white pigment had been published for the first time by Josef Riederer (1974) to whom this BBA volume is dedicated.

2 Materials and Methods

The mummy portraits investigated for this study are all from the Fayum area and date to the 2nd century AD and to the first half of the 3rd century AD (Tab. 2). They are part of the collection of Theodor Graf which had been bought by the Berlin museums in 1927. Graf had commissioned the collection in the 1880s in the Fayum area.

All five mummy portraits are depicting women and are painted either in encaustic or tempera. The wooden panel is round-topped, angled or simply rectangular.

The Severan Tondo had been painted around 200 AD on a round shaped wooden panel (Fig. 1). Besides the Roman Emperor Septimius Severus his wife Julia Domna and their sons Geta and Caracalla are depicted. Geta‘s face has been deliberately removed from the painting after his assassination in 211 (Platz-Horster, 2016). The Antikensammlung (Collection of Classical Antiquities) acquired the tondo in Paris in 1932. It is said to come from Egypt, but the precise find spot is unknown.

The Severan Tondo and three of the mummy portraits (31161,12, 31161,49 and 31161,48) were already on display in the 1980s when the Antikensammlung was still situated adjacent to the Rathgen-Forschungslabor in Berlin Charlottenburg. The objects on display had been described briefly by Heilmeyer (1988, p. 372 ff).

The group of mummy portraits has been chosen to include portraits made in different techniques: encaustic as well as tempera. Additionally, the Severan Tondo was chosen which is made in tempera technique. The measurement spots of the μ-XRF measurements and the MDRS on the portraits are documented in Fig. 2 to Fig. 7.

The analytical protocol followed by the Rathgen-Forschungslabor was limited to non-invasive methods, especially μ-X-ray fluorescence analysis and microscopic diffuse reflection spectroscopy. The pigments and colourants used on the portraits were in the focus of the investigation. The analyses were completed by Vis, IR and UV imaging techniques on the objects from the Berlin collection, as well as polarized light microscopy, X-ray diffraction, gas chromatography-mass spectroscopy and other techniques on samples from other objects from the same context by partners within the ISIMAT Project. The results are reported elsewhere (Dietemann *et al*., 2017; Sand, Fugmann, *et al*., 2017; Sand, Thieme, and Rommel-Mayet, 2017).

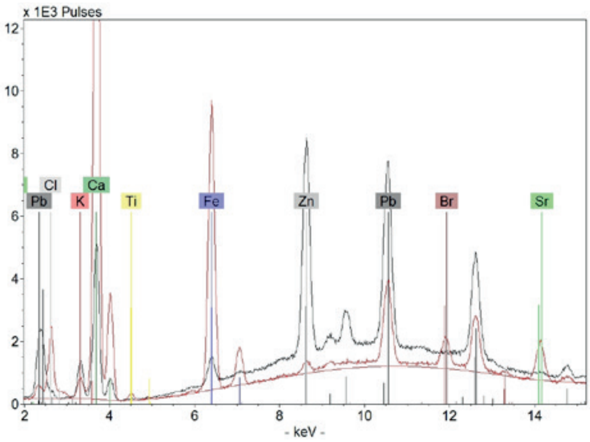


Fig. 9: µ-XRF spectra of measurements from wood support; black: 31161,12 Spec 19 (note Zn); red: 31161,52 spec 15 (note Cl und Br)

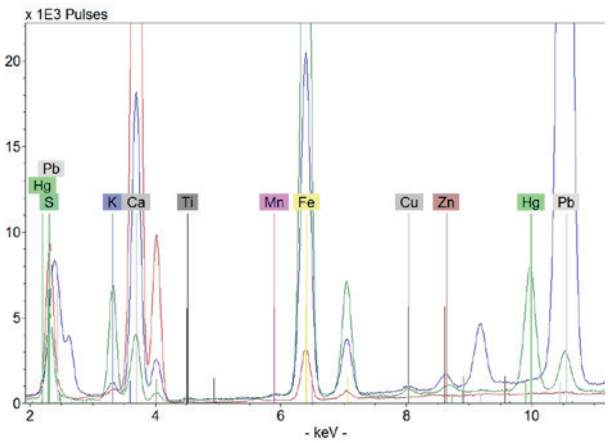


Fig. 10: µ-XRF spectra of white colourants, green: 31329 spot 1 (white highlight on red) ; blue: spot 14 of 31161,49 (white eye); red: spot 16 in 31161,48 (white eye)

3 Experimental

3.1 Micro X-ray fluorescence

Set-up

Micro X-ray fluorescence analysis (µ-XRF) was performed at the conservation workshop of the Antikensammlung using a Bruker ARTAX spectrometer equipped with a Mo target and SDD detector. Measurements were performed using the following setup: 45 kV voltage, 500 µA current, 100 s accumulation time, He flux, no filter. The working distance was about 1 mm and the spot size about 100 µm. The instrument had an XYZ motorized head and a camera-laser system for sample positioning.

Data evaluation and interpretation

XRF in general is an elemental analytical method. In He-atmosphere, elements heavier than aluminium can be detected unambiguously even in small quantities. As XRF only gives elemental information, it cannot identify organic colourants or the mineralogical composition.

The identification of lead in a white area is commonly explained by the use of lead white (a lead carbonate), whereas the same analytical result in a red area will lead to the conclusion that presumably red lead had been used. The indication of a pigment by µ-XRF is therefore always an interpretation by comparing visual appearance of the sample spot with the detected elements.

When looking at the µ-XRF spectra it has to be kept in mind that the peak of two signals cannot always be compared directly, since the sensitivity for elemental signals is not uniform over the whole range of the spectrum. As an example, the sensitivity for calcium is low as compared to copper. Therefore, in the presence of Egyptian Blue (cuprorivaite: $CaCuSi_4O_{10}$), with the same amount of calcium and copper atoms, copper will give a much higher signal compared to calcium.

3.2 Microscopic diffuse reflectance spectroscopy

Set-up

Microscopic diffuse reflectance spectroscopy (MDRS) has been carried out using a Vis-spectrometer (Zeiss PDA Vis spectrometer, type MCS621 VIS II) coupled with a stereo zoom microscope (Zeiss SteREO Discovery V8 stereo microscope with 8x manual zoom). A more detailed description of the device used can be found elsewhere (Röhrs and Stehr, 2014). For the measurement no pinhole was used resulting in a selected area for the measurements with a diameter of approx. 1.6 mm at a zoom factor of 2 (Fig. 8). The obtained reflectance spectra are compared to spectra from reference material in order to identify possible colourants dyes (Johnston-Feller, 2001).

4 Results

4.1 Wood preparation

The tempera paintings were carried out on a gypsum ground layer. There was no such layer in the encaustic portraits from the Berlin collection. In two encaustic portraits, chemical elements were identified in the wooden panel, which are untypical for wood. In 31161,12, the analysis of the wooden panel, at a spot where the layer of paint has flaked off, indicated the presence of zinc. In a very similar position on 31161,52 chlorine and bromine were detected (Fig. 9). The wooden panel had not been investigated for all objects, only occasionally where the wood was easily accessible from the front. Therefore, this

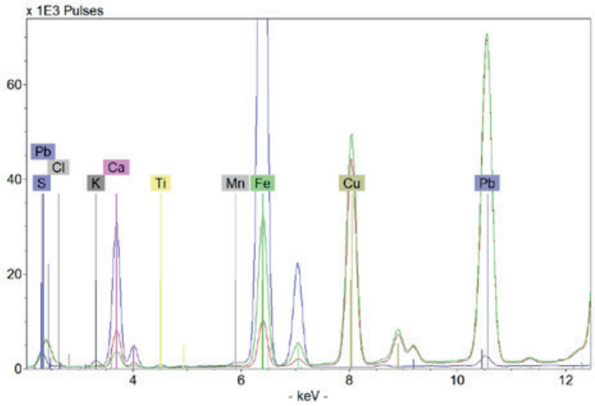


Fig. 11: µ-XRF spectra of blue and violet areas; red line: 31161,52 spot 9 (blue particle); green line: 31161,12 spot 20 (blue necklace); blue line: 31161,48 spot 4 (violet eye shade)

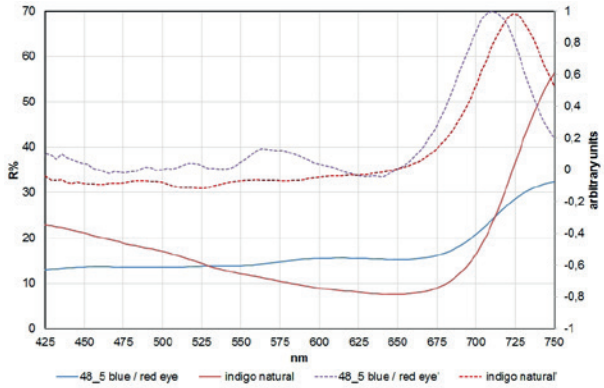


Fig. 12: MDRS measurement of spot 5 in portray 31161,48; reference spectrum of indigo.

result is difficult to generalize. In both cases the elements, Zn and Cl / Br respectively, were found in the wood but not in the layers of paint; this might indicate a preparation or treatment of the wood preceding the painting process. The purpose of such a preparation or treatment remains unclear.

4.2 White

Typical elements in the white layer were calcium or lead. Examples of spectra from the portraits 31161,48 and 31161,49 are shown in Fig. 10. The high signal of calcium and sulphur in 31161,48 spot 16 (white eye) suggests the use of gypsum rather than calcium carbonate. In the measuring spots 1 and 11 of the tondo neither calcium nor lead were found in higher quantities. Potassium, aluminium and sulphur are present and suggest the use of another white pigment, which was difficult to identify by XRF.

The mercury found in the spot 1 on the tondo, visible in the corresponding spectrum in Fig. 10, originates probably from the underlying pink or red layers of paint based on vermillion. In the portraits 31161,12, 31161,27, 31161,49 and 31161,52, lead white is the dominant white pigment.

4.3 Blue

A copper pigment was identified for the blue in 31161,52 spot 9 (blue particle) and 31161,12 spot 20 (necklace) by µ-XRF (Fig. 11). The species of the copper compound cannot be determined more specifically by µ-XRF. Judging from previous analysis (Cartwright and Middleton, 2008; Corcoran *et al*., 2010; Verri, 2009) the commonly used blue pigment is Egyptian Blue, which has been used pure or mixed with other colourants to give brown, green or pink hues. In some of the analysed blue and violet spots no copper was identified (i.e. blue 31161,27 spot 16; 31161,48 spot 4 and violet hues of 31161,12 spot 10 and 21; 31161,48 spot 13). The analysis of iron in the violet hues suggested the use of (red) ochre, but a blue component mixed with the red to give a violet was not found. The most probable colourant to be used in these spots is indigo. For the 31161,48 spot (eye shade) a corresponding MDRS analysis had been carried out. It is possible to identify indigo with the method of reflection spectroscopy (Bartoll *et al*., 2007). The reflection spectrum of indigo is shown in Fig. 12 together with the spectrum of MDRS spot 5 from 31161,48. The reflection spectra of sample spot and reference do show some differences, because the colours of the two measured areas are different. The first derivative of the sample spot spectrum has one large maximum (indicating the highest gradient in the reflection spectrum) in the red part of the spectrum. This feature is very similar to the first derivative of the indigo spectrum.

Lapis Lazuli is a stone which had been used in Ancient Egypt. Lazurite, or natural ultramarine (basically powdered lapis lazuli), would be another possible blue pigment as well as the copper mineral azurite. These two blue pigments had never been identified on this type of objects, although they might have been occasionally used as pigments in Ancient Egypt (Heywood, 2010).

4.4 Red

The most common red colorant is red ochre. Iron had been identified in all red spots. On the tondo also mercury was found, which indicated the use of vermillion as red pigment. Arsenic was not found excluding the use of realgar.

The red lead pigment minium is challenging to analyse by XRF if the presence of lead can be equally interpreted as lead white. However, on 31161,27 in spot 4 (red, inner corner of eye) the use of minium is quite

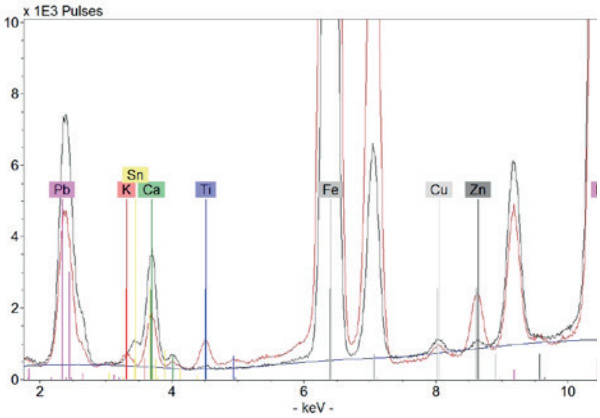


Fig. 13: Comparing two µ-XRF spectra from the eye of 31161,27; red: 31161,27 of spot 4; black: 31161,27 of spot 3

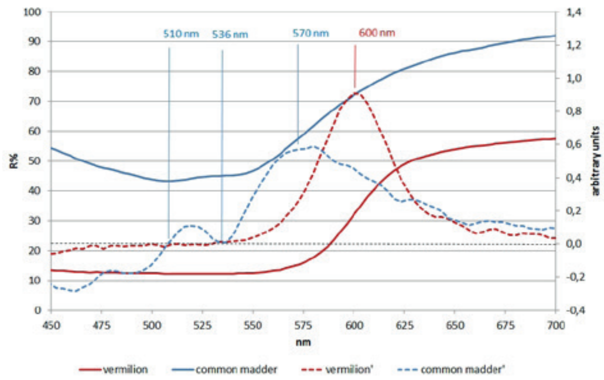


Fig. 14: reference spectra of an inorganic red (vermilion) and one organic red (common madder), the dotted lines are the first deviation of the measured spectrum.

probable. Traces of tin and a higher lead amount compared to other red spots including the eye (e.g. 31161,27 in spot 3 upper eyelid) are present in this spot. This, together with the smaller amounts of ochre-typical elements like iron and titanium, are indications of the use of minium. The spectra are compared in Fig. 13. Tin had been discussed as a trace element for red lead (minium) made from litharge formerly used in silver purification (Walton and Trentelman, 2009). However, further analysis will be needed to confirm the presence of minium here, as the use of lead white with an organic colourant cannot be ruled out.

A further point worth noting is the presence of zinc in the red spots on the objects 31161,27 and 31161,49. Smaller quantities of zinc have also been found in many red hues on 31161,48 and only in one spot on the tondo 31329 (Tab. 3). Additionally the presence of a trace of zinc was detected in blue/red hues: in 31161,27 spot 16 (mouth shade) and 31161,48 spot 4 (eye shade). Thanks to the very high sensitivity of the µ-XRF device for zinc, also small quantities of zinc are picked up. Possibly the zinc content might be related to a red organic colorant. The use of red organic colorant on 31161,27, 31161,48 and 31161,49 is suggested by the MDRS finds. As shown in previous studies and listed in Tab. 1, madder is the most probable organic colourant.

Inorganic pigment spectra have one absorption band, whereas many organic colorants, such as anthraquinonic colorants have double absorption bands in the range from approximately 500 to 550 nm (Aceto *et al*., 2014; Johnston-Feller, 2001, p. 227). In Fig. 14 examples of inorganic pigments and organic colorants are shown. The first deviation of the madder reference spectra is more structured in the 500 to 570 nm-region, similar to the spectra from spot 1 of 31161,27 in Fig. 15.

Identification of the colourant molecule by Vis diffuse reflectance spectroscopy is difficult to achieve because of the complex mix of colorants, pigments and binding media on several layers. The analysis of samples from the red by an analytical method, like High-Performance Liquid Chromatography (HPLC), would allow identifying the red colorant unambiguously.

4.5 Yellow and gold

In the literature mostly iron containing pigments like yellow ochre or jarosite ($KFe_3^{3+}[(OH)_6|(SO_4)_2]$) are proposed as colorant for yellow. The distinction between both pigments by µ-XRF is challenging, since both contain iron. Potassium which would indicate jarosite is present in traces in many spectra. However, none of the spectra from the yellow had shown an exceptional potassium content which makes the interpretation that ochre had been used more probable.

In one object 31161,48 arsenic was found in the spots 9 and 15, suggesting the use of orpiment (or parareglar) to depict the golden jewellery and embroidery on the coat.

The golden remains in the background of 31161,49 are from gold foil.

4.6 Green

Green is infrequently used on the mummy portraits and is not present on the tondo. On 31161,12 the green contains copper suggesting the use of malachite, other green copper minerals or Egyptian blue together with a yellow component. The green hue in 31161,49 spots 11 and 12 do not contain any copper, which excludes the above mentioned pigments. Probably a green earth pigment had been used in this case.

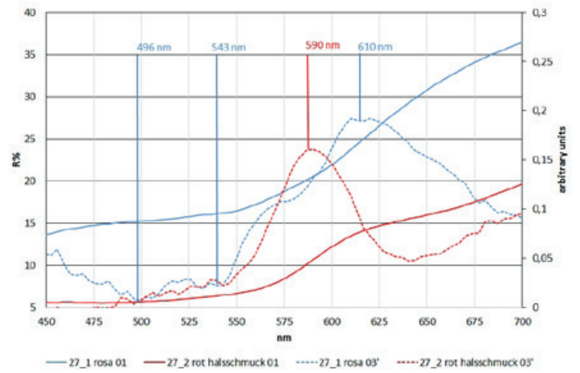


Fig. 15: Comparing two MDRS measurement 1 and 2 spots of object 31161,27. Spot 1 (in blue) rose colours from the dress probably contains an organic colorant.

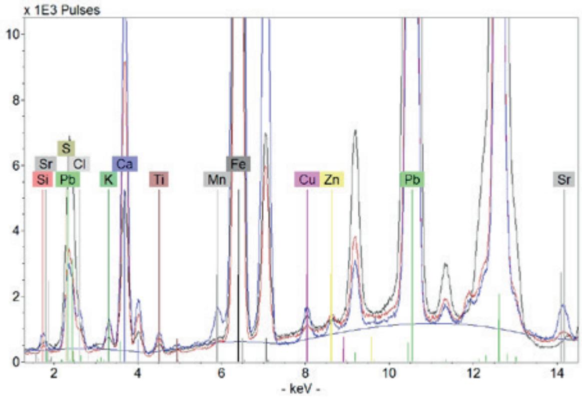


Fig. 16: comparing three µ-XRF spectra of black spots; black: 31161,12 spot 18; red: 31161,27 spot 13; blue 31161,52 spot 12.

4.7 Black

The black pigments are difficult to identify by XRF on the portraits. Carbon, the main component of carbon-based black pigments cannot be detected by XRF and the precursor used to generate the black (i.e. lamp oil, plant material, ivory, bone) could only be identified by other microscopic and analytical methods. Variations in the elemental components can be observed (Fig. 16), maximum contents of silicon (Si), potassium (K), titanium (Ti), manganese (Mn) and copper (Cu) can be found in 31161,52 spot 12. The presence of a mineral constituent could also indicate the use of a black earth (e.g. black chalk or black slate), but it is difficult to be certain, as the black might be as well have been mixed with other pigments such as ochre which can contain the same mineral constituents.

4.8 Overview of the results of the non-invasive analyses

In the results of the µ-XRF measurements are presented according to objects and colour. The individual measurement spots can be identified by the numbers in the corresponding field. The results of the MDRS measurements are included in the table. Their measurement spots can be identified by the prefix MRDS to the number. The spot positions are shown in the Figures 1 to 6.

5 Discussion of the results

5.1 Analytical challenges of the non-invasive approach

Tab. 3 summarizes the pigments used for the tondo and the five mummy portraits. The identification of the pigments by the two methods used in this study is not always unambiguous. As an example, the white pigment in the tondo can be mentioned: In the publication of the ISIMAT project by Dietemann *et al* (2017, 203) it is reported that alunite had been identified in the flesh tone of a male mummy portrait from Wurzburg (H2196). Alunite is a hydrated aluminium potassium sulphate and may include a substantial amount of sodium to replace potassium, which is the case for the mineral identified in the Wurzburg portrait. It was proposed that alunite was equally used in the Severan Tondo, as it would explain the presence of aluminium and potassium (Sand, Fugmann, *et al*., 2017). The high aluminum and potassium contents in the white of the tondo suggest the use of alunite as white pigment. However, further analysis will be necessary to confirm this hypothesis..

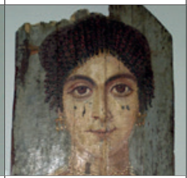
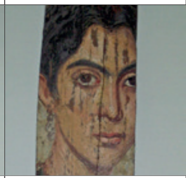
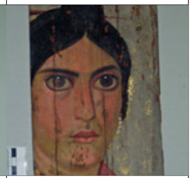
The use of huntite (manganese calcium carbonate) as white pigment as identified by Riederer was not confirmed by the analytical results from these portraits, although it has to be stressed that huntite, again, is difficult to detect by the µ-XRF used in this study. Manganese, the element of huntite which could indicate the presence of this pigment, is only detectable if it is present in large quantities. Riederer used X-ray diffraction on samples for the identification of huntite in the Nubian ceramic.

Equally the question if minium (red lead) was used in further red areas (additionally to 31161,27 spot 4) or if all the lead is present as lead white and the distinction of jarosite and/or yellow ochre as colorant for yellow could not by solved by µ-XRF. This shows the limits of this analytical approach, which was not supposed to be all encompassing but only complementary within the ISIMAT project.

5.2 Pigment palette as a function of the painting technique

Some differences in the palette of pigments have been found in the studied portraits. The portraits no. 31161,12, 31161,27, 31161,49 and 31161,52 contain lead white. Other white pigments such as alumina-silicates and gypsum have been found on the tondo and the portrait

Tab. 3: Summary of results obtained on the Berlin mummy portraits and the tondo

Layer / Colour	31161,52	31161,27	31161,12	31329	31161,48	31161,49
						
preparation layer	15 - wood preparation (?) Contains Cl and Br		19 – wood preparation: zinc compound calcium carbonate (e.g. chalk?), lead white,?	Grounding: 24 - gypsum	Grounding: 2 - gypsum	
white	No pure white on object but probably lead white	5, 10 - lead white	7, 17 - lead white	1, 11 – in the white probably a **earth/mineral containing Al, S, K;** possibly some lead white	16 – gypsum	9, 10, 14 - lead white, some calcium-carbonate (e.g. chalk) zinc (9, 14 from red beneath?)
flesh tone light rose/ rose	2 – lead white, red ochre	8 - lead white, red ochre, zinc MDRS 1: indication of org. dye	4, 5 - lead white, red ochre,	4, 5, 12, 15, 20 – red ochre, **vermillion**, gypsum, some lead white	1 – gypsum, red ochre some zinc MDRS 4: indication of org. dye	2, 13 - lead white, red ochre, some calcium-carbonate (e.g. chalk) **zinc** (2, 13)
flesh tone ochreous	-	1, 6, 7, - lead white, yellow ochre zinc (7)	8, 9 - lead white, ochre,	21, 22, 23 - ochre, **vermillion**, gypsum, some lead white	6, 8, 11 - gypsum, yellow ochre	1, - lead white, yellow ochre, **zinc compound**
rose	11, - lead white, ochre MDRS 4: indication of org. dye	-	-	7 – red ochre, gypsum, some lead white, **earth(s)/ mineral(s) containing Al, Si S, K, Ti**	-	-
red	3, 4, - rot ochre, lead white, strong **copper** in one spot (3)	2, 3, 4, 15 - red ochre, lead white, spots with **zinc (strong: 3, 15, few: 2)** - in one spot (4) **tin**	6, 16 - red ochre, lead white,	10, 14, 17 - ochre, **vermillion**, gypsum, some lead white, **zinc** (10)	7, 10, 14, 18, 19 – red ochre, gypsum - trace **lead and zinc** (14, 18) MDRS 7: indication of org. dye	3, 4, 5, 8, 15- Red ochre, lead white, some calcium-carbonate (e.g. chalk) zinc (3, 4, 5, 8, 15) MDRS 1: indication of org. dye
orange	-	-	-	3 – red ochre, **vermillion**, strong lead white or yellow/ red?	-	-
yellow	5, 6, 16 – yellow ochre, (jarosite?) lead white	17 - lead white, yellow ochre (jarosite?)	-	25 – yellow ochre (jarosite?), gypsum, some lead white	9, 15, - gypsum, (jarosite?) yellow ochre, **orpiment**	17, 18, - lead white, yellow ochre, (jarosite?) some calcium-carbonate (e.g. chalk)
gold	-	-	-	-	-	6 – gold foil
green	-	-	12, 13, 15 - green copper pigment, iron compound (ochre/ green earth?), lead white	-	-	11, 12, - lead white, iron containing pigment (ochre/ green earth?) zinc (11, 12 from red beneath?)

Tab. 3: continued

Layer / Colour	31161,52	31161,27	31161,12	31329	31161,48	31161,49
blue	9 – (blue particle) blue copper pigment (azurite), lead white, iron pigment (ochre/ green earth?)		20 – (blue /green) blue or green copper pigment	-	4, 5 (blue with red hue) - gypsum, iron signal (red ochre) zinc (4) MDRS 5: indigo	-
brown	1 - dark ochre, lead white	12 - lead white, some ochre with traces of **chrome** and **zinc**	-	8, 9, 18 - ochre, gypsum, some lead white In spot 9: **vermil-lion**	-	-
violet	-	16 (blue/vio-let)- lead white, blue component unclear **zinc**	10, 21 - red ochre, lead white, blue component unclear	-	13 - gypsum, red ochre, lead (white or red?) MDRS 6: indicati-on of org. dye	-
grey	7, 8, 10 – iron con-taining compo-nent, lead white, copper compound (azurite)	Background: 9, 11, lead white, some iron and zinc cont-aining component Dress: 14 - lead white, compo-nent(s) containing Si, K, Ti, Fe Zn	1, 11 - lead white, iron containing component	6 - gypsum, iron containing com-ponent 19 **pentimenti**: calcium carbo-nate e.g. chalk/ gypsum? grey component unclear	3 - gypsum, iron containing com-ponent	7 -lead white, some iron con-taining compo-nent, calcium-car-bonate (e.g. chalk)
black	12, 13, 14 - iron containing component, lead (white?),	13 - lead (white?), iron containing component, traces of Si, K, Ti (black-earth / chalk?)	2, 14, 18 - iron containing component, lead white, potassium (carbon black?)	13 - iron cont-aining compo-nent, gypsum, some lead (white?)	12, 17 - gypsum, iron containing component, lead (white?) zinc (12)	16 - lead (white ?),iron containing component, some calcium carbonate (e.g. chalk) zinc (16)

no. 31161,48, respectively. Among the four lead white-containing paintings three are made with encaustic and one with tempera. The encaustic paintings seem to have been mainly made with lead white. Salvant *et al* (2017) have also shown that all paintings with wax or beeswax contain lead white. The type of white pigment used in the tempera paintings is more variable and includes lead white, calcium carbonate and another one, possibly alunite.

The palette of pigments of the tondo differs from that of the mummy portraits in a second aspect: the use of vermilion as red pigment. The mercury containing pigment was apparently used together with ochre. Vermilion has also been used on mummy portraits as had been shown by Salvant *et al* (2017). In their work, vermilion was identified in one female portrait (with wax as binding medium) out of eleven studied objects: The pigments vermilion (only on the tondo in this study) and orpiment (only on no. 31161,27) have apparently rarely been used in portraits.

The occasional presence of zinc is an interesting aspect in the reddish spots. It is predominantly found in the red pink or flesh tone of the three portraits no. 31161,27, 31161,48 and 31161,49 (and in one red spot of the tondo 31329). This might be related to a certain use of possibly a red lake, as on all three mummy portraits MDRS indicated the presence of organic colorants. Among the three portraits two are painted with tempera (no. 31161,48 and no. 31161,49) and one encaustic portrait (no. 31161,27).

6 Conclusion

A broad range of pigments was identified by the chosen analytical protocol: lead white, red lead, ochre, vermilion and realgar. The MDRS could evidence the presence of indigo and organic red colourant, but the exact identification of the dyestuff is still open.

The presence of some inorganic pigments like red lead, jarosite and alunite might need further investigation to be definitely confirmed. Equally the question of the blue and green copper pigments could be further investigated by µ-Raman and *in-situ* XRD in a second analytical campaign on the portraits.

For the white pigment there seems to be a preference for the use of lead white in encaustic paintings. Vermillion and orpiment had only been used infrequently.

Further analysis is required to draw well-founded conclusions whether the choice of pigments depends on painting technique, subject of the image, painting workshop/ provenance or production date.

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