

TECHNICAL PAPER

PAINT INVESTIGATION OF ALTAR AND PULPIT IN THE CHURCH OF ST. MARY, VIGALA, ESTONIA

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After an illegal over-painting of the seventeenth-century altar and pulpit in Vigala St. Mary's church in Estonia, comprehensive paint layer investigations and chemical analysis studies – using optical microscopy, scanning electron microscopy - energy dispersive X-ray spectrometry (SEM-EDS) and micro attenuated total reflectance Fourier transform infrared (micro-ATR FT-IR) spectroscopy – were carried out. The history of the colour scheme and paint compositions of the altar and the pulpit could be revealed to great extent. This is the first study of this kind in Estonia and it is expected to provide reference material for similar investigations in the Baltic and Northern-European region.

1 Introduction

St. Mary's church in Vigala was probably built at the end of the thirteenth century.^{1,2} The altar and the pulpit of the Vigala church are among the most beautiful and original woodcarving works preserved in rural churches in Estonia,^{1,2,5} and are two of the most important interior elements of that church. Both were made by Christian Ackermann, a leading woodcarver in Estonia in the second half of the seventeenth century. He worked as a free master, independent from the guild-regulations, filling mainly noblemen's orders (prevalently altars, pulpits and coats of arms).^{3,4} The altar of the Vigala church was made during the second half of the 1680s and the pulpit was made during the late 1670s or at the beginning of 1680.

In autumn 2005, upon the initiative of the priest of the Vigala St. Mary's church and without permission from the National Heritage Board of Estonia, the altar, pulpit and other furnishing objects were over-painted with exterior and artists paints (alkyd resin and oil paints) leading to the loss of their historical value.

Initiated by this unfortunate over-painting, a comprehensive historical and material study of the over-painted altar and pulpit was carried out with the aim to elucidate the colour schemes and paint materials used

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during different time periods and to decide whether to remove the over-painting or not.

Historical investigations showed that recurrent reconstruction works had been carried out in the church in the nineteenth and twentieth centuries. The reconstruction works had also involved repairs and over-painting of the altar and the pulpit on several occasions. Some limited information on these works is available in archival materials. For example, it is known that in 1888 the altar and the pulpit were gilded, silvered and maybe some other over-paintings were done. However, the history of these works of art is generally poorly known.

The altar's and pulpit's colour scheme was investigated visually, using optical microscopy in reflected light, as well as with instrumental methods, including scanning electron microscopy - energy dispersive X-ray spectrometry (SEM-EDS) and micro attenuated total reflectance Fourier transform infrared (micro-ATR FT-IR) spectroscopy.

2 Materials and Methods

Samples for determining binder, pigments and additives were taken from various places of the altar and the pulpit with a sharp scalpel and tweezers. The samples were multi-layered and some fragile ones broke into several layers under the pressure of the scalpel. Some of these layers were analysed separately.

For a good understanding of the paint layers, windows and cross-sections were made. Windows were created by mechanically scraping away paint, layer by layer, with a sharp scalpel. Figures S1-S5 in the Supplementary Information indicate the locations of windows and samplings. On the altar, 97 windows (Tables S1, S3, S4, S5) were made and on the pulpit 67 (Tables S2, S6, S7, S8). Cross-sections were prepared from 34 samples of the altar and 23 samples of the pulpit. Technovit 2000 LC polymer (single-component mono- and difunctional methacrylate, 2000 LC, Heraeus Kultzer GmbH; Hanau, Germany) was used for making cross-sections.

The cross-sections were examined with the help of an optical microscope (Examet, Union Optical; Tokyo, Japan) in reflected light. Objects were photographed with a digital camera (Coolpix 990, Nikon). Generally a magnification of 5-20 times was used. Semi-quantitative elemental analyses of samples (cross-sections of paint specimen) were carried out with a scanning electron microscope - micro-analyser JXA-840 (JEOL; Tokyo, Japan) equipped with an energy dispersive X-Ray

spectrometer (Voyager, Noran; Middleton, USA), abbreviated as SEM-EDS. This method allowed detailed surface analysis at high imaging magnifications and elemental analysis of small subsurface areas, thereby enabling to identify many inorganic pigments and fillers.^{6,7} Energy of probe electrons was 20 keV. Some cross-sections were coated with a thin platinum film using magnetron sputtering, which increased sample surface conductivity and prevented their charging. As a rule, different layers of cross-sections were analysed separately. Some sample layers, which resulted from broken samples, were fixed on a vacuum-clean double-sticker layer and analysed as such. 23 different layers were examined with SEM-EDS.

Some sample layers were additionally analysed by micro-ATR FT-IR spectroscopy. FT-IR spectra were measured using a Nicolet 6700 spectrometer with Smart SplitPea micro-ATR accessory (Thermo; Waltham, USA). The FT-IR spectrometer was equipped with a DLaTGS Detector with CsI Window, a Vectra Aluminum Interferometer and had a sealed and desiccated optical bench (CsI optics). The accessory consisted of a diamond ATR crystal with sample area diameter of 0.5 mm and a calibrated pressure applicator with optional 50x ViewThruPress (applies up to 6 lbs of pressure). The following spectrometer parameters were used: resolution 4 cm⁻¹, spectral range 225-4000 cm⁻¹, number of scans: 128, level of zero filling: 0, apodization: Happ-Genzel.

Spectra on unknowns were interpreted by comparison with reference spectra of different materials available from our laboratory and from the literature.

3 Results and discussion

After preliminary investigation of the cross-sections and windows, it was evident that information about the chemical composition of the layers – in particular, about the pigments used – was needed in order to elucidate the history of the altar's and the pulpit's colour scheme. In those cases where the optical microscopy and SEM-EDS results were not conclusive for the identification of the pigments (this was the case with seven layers), additional analyses were performed using the micro-ATR FT-IR spectroscopy (Figures S6, S7 in the Supplementary Information).

The results of the SEM-EDS and micro-ATR FT-IR analyses are shown in Tables 1 and 2, referring to the altar and pulpit, respectively.

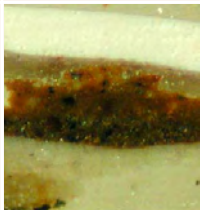
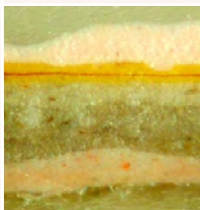
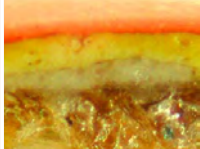
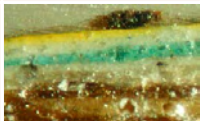

Sample No	Locations of the windows and cross-sections	Picture of cross-section	Description of the windows	Layers analysed	Elements in the EDS spectra	Results
1.	Backside of the altar		only one layer scraped for chemical analysis	Black	C, O, Mg, Al, Si, P, S, K, Ca, Fe	charcoal black (C), kaolin ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$), chalk (CaCO_3), some other additives; the binder is a protein.
2.	On the horizontal plane W _a -5 CS _a -3		4 - White, grey (final layer) 3 - Brown 2 - Grey (greyish beige) 1 - Black	Brown	C, O, Fe, Na, Zn, Al, Si, P, S, Cl, K, Ca, Ba, Mn	Umber ($\text{Fe}_2\text{O}_3 + \text{MnO}_2 + \text{clay}$ ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$)), chalk (CaCO_3), probably some barium salt(s) (BaCO_3 , BaSO_4), other additives.
				Grey	C, O, Pb, Ca	Lead white ($2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$), charcoal (C), chalk (CaCO_3).
				Black	C, O, Mg, Al, Si, P, S, Ca	charcoal black (C), chalk (CaCO_3), silicates, other additives.
3.	On the basis of the side wings of the ornament W _a -11		only one layer scraped for chemical analysis	Grey	C, O, Mg, Al, Si, Pb, Cl, Ca, Fe	Lead white ($2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$), charcoal (C), chalk (CaCO_3), silicates; the binder is an oil.
4.	On the carving and profiles W _a -11 _a		only one layer scraped for chemical analysis	Grey	C, O, Mg, Al, Si, Pb, Ca, Fe	Lead white ($2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$), charcoal (C), chalk (CaCO_3), silicates, other additives.
5.	On the right of the angel's face W _a -8 CS _a -1		6 – Rose (final layer) 5 – Gold leaf 4 – Yellow 3 – Grey 2 – Rose 1 – Black	Yellow	C, O, Na, Pb, Ca, Cr, Zn	chrome yellow (PbCrO_4), chalk (CaCO_3), silicates, maybe zinc white (ZnO); the binder is an oil.
				Grey	C, O, Pb, Ca	Lead white ($2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$), charcoal (C), chalk (CaCO_3).
				Rose	C, O, Pb, Ca	Lead white ($2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$), red lead (Pb_3O_4), chalk (CaCO_3).
6.	Lower part of the pillar of allegory W _a -17 CS _a -4		4 – Red (final layer) 3 – Gold leaf 2 – Yellow 1 – Grey	Yellow	C, O, Ba, Pb, Ca, Cr, Zn	chrome yellow (PbCrO_4), chalk (CaCO_3), silicates, maybe zinc white (ZnO), probably some barium salt(s) (for example BaCO_3); the binder is an oil.
				Grey	C, O, Pb, Ca	Lead white ($2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$), charcoal (C), chalk (CaCO_3).
7.	The lowest blue layer of the coat of arms W _a -56		only one layer scraped for chemical analysis	Blue	C, O, Co, Mg, Al, Si, Pb, K, Ca, Fe, Zn	Smalt ($\text{K}_2\text{O} \cdot \text{SiO}_2 \cdot \text{CoO}$), chalk (CaCO_3), silicates (mineral additives), other additives, lead white ($2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$) may be present.
8.	Sculpture „Love“ Upper part of the robe W _a -86 CS _a -12		4 – Gold leaf 3 – Yellow 2 – Blue (greenish-blue) 1 – Grey	Greenish-blue	C, O, Ba, Zn, Na, Mg, Al, Si, S, Pb, Cl, K, Ca, Fe	Main compound is Prussian blue ($\text{Fe}_4[\text{Fe}(\text{CN})_6]_3$), chalk (CaCO_3), barium sulphate (BaSO_4), silicates and zinc white (ZnO); the binder is an oil. The greenish tone may be due to green earth or to Prussian blue.
9.	Sculpture „Love“ Lower part of the robe W _a -85 CS _a -13		4 – Dark brown 3 – Light grey 2 – Red 1 – Grey	Red	C, O, Na, Si, Hg, S, Cl, K, Ca, Ba, Zn	Vermilion (or Cinnabar) (HgS), maybe zinc white (ZnO) or lithopone ($\text{ZnS} + \text{BaSO}_4$), chalk (CaCO_3), barium carbonate (BaCO_3) and silicates (mineral additives).

Table 1. Results of the SEM/EDS and micro-ATR FT-IR analysis of the altar samples. The layers are numbered starting from the uppermost (surface) layer. W_a: window on the altar; CS_a: cross-section on the altar.

3.1 Corpus of the altar and pulpit

The samples of the altar and the pulpit were observed layer by layer. The results indicated that the colour scheme of the altar has historically been somewhat different from the colour scheme of the pulpit. Moreover, it appeared that overpaintings had not been done randomly, but in specific time periods only. A detailed discussion on the paint layers is presented below. The first layer is the one that is attached directly to the wood surface.

3.1.1 First layer

In the altar corpus samples a black paint layer (Table 1, Table S1) was identified as the first one and it covers almost the entire altar corpus and

several (but not all) of the altar sculptures. According to the SEM-EDS results the pigment of the first black layer has a high carbon content and contains also some silicates. Additional information was obtained from the IR spectrum (Figure S6): the presence of calcium carbonate (CaCO_3) was confirmed, kaolin ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) was identified as filler and a protein binder was detected. According to the IR spectrum (Figure S6) the black pigment is not bone black ($\text{C} + \text{Ca}_3(\text{PO}_4)_2$), because the characteristic phosphate bands at 2010 cm^{-1} and 605 cm^{-1} , 565 cm^{-1} are absent. So, the black pigment may be charcoal black (C), with chalk, kaolin and other additives added. The charcoal black layer can be a preparative layer. Differently from the altar, the cross-sections and windows of the corpus, the sounding-board and the balustrade of the staircase of the pulpit do not




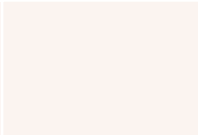
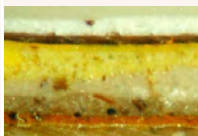
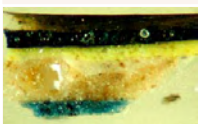
Sample No	Locations of the windows and cross-sections	Cross-section	Description of the windows	Analyse d layers	Elements in the EDS spectra	Results
1	On the coil-pillar W _p -23 CS _p -14		5 – White (final layer) 4 – Gold leaf 3 – Yellow 2 – Grey 1 – Light-brown	Grey	C, O, Pb, Ca	Lead white (2PbCO ₃ •Pb(OH) ₂), charcoal (C), chalk (CaCO ₃).
2	On the corpus of sounding-board W _p -47 CS _p -11		5 – Light grey (final layer) 4 – Dark brown 3 – Light-blue 2 – Grey 1 – Gold leaf	Light-blue	C, O, Na, Mg, Al, Si, Pb, S, Ca, Ba	Lead white (2PbCO ₃ •Pb(OH) ₂), chalk (CaCO ₃), barium sulphate (BaSO ₄), silicates. BaSO ₄ has intensive bands in the IR spectrum.
3	On the corpus of pulpit and cartouche W _p -20 CS _p -21		6 – white (final layer) 5 – Dark brown 4 – Light-blue 3 – Grey 2 – Black 1 – Gold leaf	Brown	C, O, Na, Al, Si, Pb, S, K, Ca, Ba, Fe, Zn	Brown ochre (Fe ₂ O ₃ + aluminosilicate), chalk (CaCO ₃), probably some barium salt(s) (BaCO ₃ , BaSO ₄).
				Light-blue	C, O, Na, Mg, Al, Si, Pb, S, Ca, Ba	Lead white (2PbCO ₃ •Pb(OH) ₂), chalk (CaCO ₃), barium sulphate (BaSO ₄), silicates.
5	On the side panel of the balustrade of the staircase W _p -9 CS _p -1		3 – Grey (final layer) 2 – Brown 1 – Grey	Brown	C, O, Na, Mg, Al, Si, Pb, K, Ca, Ba, Fe, Zn	Brown ochre (Fe ₂ O ₃ + aluminosilicate), chalk (CaCO ₃), barium carbonate (BaCO ₃).
6	On the leaf of acanthus W _p -67D CS _p -7		6 – White (final layer) 5 – Gold leaf 4 – Yellow 3 – White 2 – Grey 1 – Light-brown	Yellow	C, O, Na, Si, Pb, Ca, Ba, Cr, Zn	Chrome yellow (PbCrO ₄), chalk (CaCO ₃), silicates, maybe zinc white (ZnO), other additives; the binder is an oil.
				Light-brown	C, O, Fe, Mg, Al, Si, Pb, K, Ca, Mn, Au	Umber (Fe ₂ O ₃ + MnO ₂ + clay (Al ₂ O ₃ •2SiO ₂ •2H ₂ O)), with chalk (CaCO ₃), other additives.
7	On the coat of arms blue background W _p -65 CS _p -4		5 – Dark blue 4 – Gold leaf 3 – Yellow 2 – Greyish-beige 1 – Blue	Blue	C, O, Mg, Al, Si, Pb, K, Ca, Fe, Co	Smalt (K ₂ O•SiO ₂ •CoO), chalk (CaCO ₃), silicates, other additives. Lead white (2PbCO ₃ •Pb(OH) ₂) may be also present.

Table 2. Results of the SEM/EDS micro-ATR FT-IR analysis of the pulpit samples. The layers are numbered starting from the uppermost (surface) layer. W_p: window on the pulpit; CS_p: cross-section on the pulpit.

have this first black layer (Tables S1 and S2). The corpus of the pulpit was presumably grey, as is also the case in some small parts of the corpus of the altar.

3.1.2 Second layer

The second colour layer on the altar and the pulpit is a grey layer, which covers almost the entire pulpit and most of the corpus, as well as the construction and carving details of the altar (Table 1 and 2, Table S1 and S2). According to the SEM-EDS results the chemical composition of the grey layer on the altar and the pulpit is similar: white lead mixed with charcoal, chalk and some silicates. The IR spectra confirmed these findings and allowed to detect oil as the binder. According to all available evidence, the grey colour scheme must be considered the earliest one of the altar and the pulpit. Removal of (some other) original paint layer before painting grey is highly improba-

ble as there is no evidence of such practice anywhere in Estonia.

3.1.3 Third layer

Starting from the third colour layer the colour schemes of the altar and the pulpit are different and therefore, they are discussed separately.

3.1.3.1 Third layer on the altar

The third colour layer of the altar is the result of an over-painting that was done using the brown-yellow-golden colour scheme (Figures 1, 2). The brown colour (Table 1 (sample no 1), Tables S1, S3)) consists of umber and fillers (chalk and probably barium carbonate). The golden colour (Table 1 (samples no 5, 6), Tables S1, S3) has two sub-layers: beneath the actual gold layer there is a preparative yellow layer, which according to the



Figure 1. Inside view of the Vigala church in the 1920s (glass plate negative). Image from the photo collection of the art history department of the University of Tartu, Estonia.

EDS spectra has chrome yellow (PbCrO_4)⁹ as the main pigment component. This result was confirmed by FT-IR spectroscopy: in the spectra of the yellow layers (Fig S6) absorption bands of chrome yellow (PbCrO_4) were present. The most characteristic of them are at ~ 858 and ~ 833 cm^{-1} .⁸ According to the SEM-EDS data these layers contain also zinc and barium (sample no 6). The chromates of barium and zinc have somewhat similar IR spectra, but there are distinct differences: the two bands in the range of $800\text{--}900$ cm^{-1} are at ~ 900 and ~ 860 cm^{-1} and ~ 875 and ~ 800 cm^{-1} in BaCrO_4 and ZnCrO_4 , respectively. Ba and Zn are instead present as BaCO_3 (also maybe BaSO_4)



Figure 2. The altar before the over-painting in 2005 (photo by Peeter Säre).



Figure 3. The altar after the over-painting in 2005 (photo by Jaanus Heinla, Conservation Centre "Kanut", Tallinn, Estonia).

and maybe ZnO (ZnO has a broad band in the range of $500\text{--}300$ cm^{-1}). It is also possible that the yellow layer contains instead (or besides) of ZnO lithopone ($\text{ZnS} + \text{BaSO}_4$). The binder is oil.

The historical investigation and photos (Figures 1, 2) show that in 1888 the altar was gilded and silvered and that it had a brown-yellow-golden colour scheme before the most recent over-painting in 2005 (Figure 3).² The black and white photo (Figure 1) from the 1920s shows the altar already in the pre-2005 overpaint condition, which is also documented in the latest photos – dark corpus, brown oil-colour painting, gilt ornaments, angels and pillars (Figure 2). Based on this, the third layer (yellow-golden-brown colour scheme) was most probably applied in the course of the repainting in 1888.

As mentioned above, beneath the yellow layer mostly the grey layer (second layer) is found. Hence, it can be assumed that the altar was grey in the 1840s when the church was reconstructed. The possibility that the altar was more colourful already before 1888 and the earlier paint layer was removed during the over-painting can be ruled out.

3.1.3.2 Third layer on the pulpit

The third paint layer of the entire pulpit was applied using the light-blue-brown-golden colour scheme. The corpus of the pulpit and sounding-

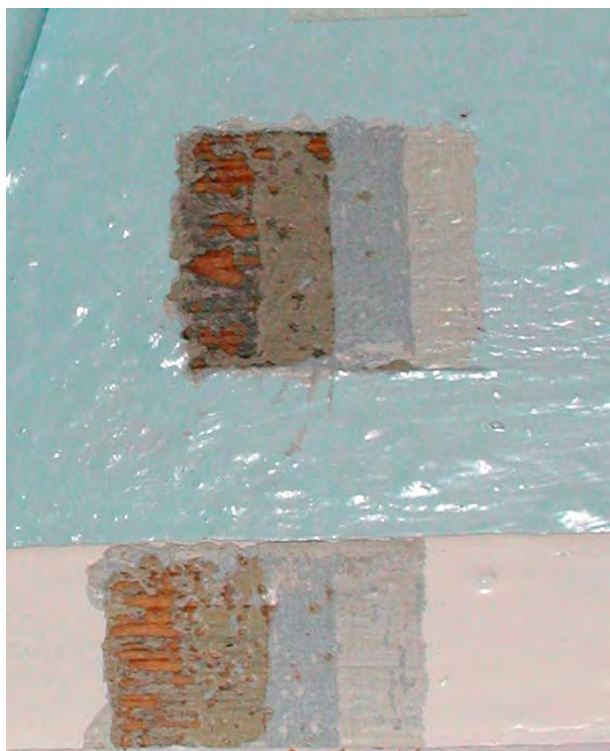


Figure 4. Windows made on sounding-board roofs side slats (Photo by Jaanus Heinla, Conservation Centre "Kanut", Tallinn, Estonia).

board and also the leg of the pulpit were light blue (Table 2: samples no 2, 3; Table S2: W_p-2 , W_p-5 , W_p-7 , W_p-42 , W_p-45 , W_p-47).

The light blue layer (Table 2; Fig 4) consists of white base and a blue pigment. SEM-EDS and ATR-FT-IR (see Fig S7) data indicated that the layers contain large amounts of lead white, calcium carbonate, barium sulphate and silicates. The binders are most probably some protein and oil. It was difficult with either SEM-EDS or ATR-FT-IR to identify the blue pigment because of its low concentration in that paint layer, as evidenced by optical microscopy, revealing only few blue pigment particles in the matrix of white colour. The SEM-EDS analysis of these particles indicated that it can be a silicate pigment. It is possible to exclude silicate pigments such as smalt¹⁰ and Egyptian blue,¹⁰ because cobalt and copper peaks were absent in the EDS spectra, respectively. Alternatively, the EDS spectra contained the peaks of all the elements of ultramarine ($3Na_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2Na_2S$).

In the third layer some areas of the pulpit were painted using a brown colour. The side panels of the balustrade of the pulpit staircase were dark in the beginning of the 20th century according to Figure 4. The respective paint layer (Table 2, sample no 5) is brown. SEM-EDS analysis of the sample indicated that the brown pigment is brown



Figure 5. The pulpit at the beginning of the 20th century (photo by H. Reimer). Image from the photo collection of the Estonian History Museum (Tallinn, Estonia).

ochre (differing from the altar's brown paint, which was umber). Similarly to the altar, chrome yellow (with some additives) was found beneath the gilding (Table 2, sample no. 6).

This high similarity of materials used between the corresponding paint layers of the altar and pulpit samples means that most probably the pulpit was repainted in the same year 1888 as the altar, although with a different colour scheme. The corpus of the pulpit was repainted in light brown. From the black and white photos of the 1920s (Figures 1, 5) it is possible to see that the colouring of the pulpit is not dark like that of the altar. A lighter colour tone has been used for the corpus. The background of the figure on the board of the corpus (Figures 1, 5) was somewhat darker. That lighter colour tone is light-blue according to cross sections and windows.

3.1.3.3 Fourth layer on the pulpit

According to the cross-sections and windows, the next extensive over-painting of the pulpit was performed in a darker brown colour tone, probably to match with the colour scheme of the altar. Only the pulpit was over-painted. The brown layer applied at that time consists of brown ochre and some fillers (Table 2, sample no 3). Historical investigations indicated that in 1927 repair works were planned in the church, but in archival documents there is no information whether the pulpit was involved in the repair works². Comparing the Figures 1 and 5 with the photo made in 1934 (Figure 6) it is possible to conclude that the pulpit and sounding-board have undergone over-painting during 1920-1934, the year 1927 falling within this time frame.



Figure 6. The pulpit after 1934. Image from the photo collection of the art history department of the University of Tartu, Estonia

During these renovation works (in 1927-1934) the altar was not repainted. Hence, the colour of the altar was then brown-yellow-golden, according to the way it was painted in 1888.

The fourth layer analysis indicated that, before the most recent over-paintings in 2005, the corpus of the altar had three and the corpus of the pulpit four paint layers. Figures 2 and 7 show the altar and the pulpit before the over-paintings, figures 3, 8 and 9 display them after the over-paintings in 2005.

3.2 Sculptures and other artistic details

The over-paintings in 2005 did not involve sculptures and other artistic details. The windows and cross-sections of the round-plastic sculptures and other carving details showed that, like the corpus altar and pulpit, the sculptures were grey before the nineteenth century. Windows and cross-sections also show that the grey sculptures were over-painted in 1888 or, in some cases, before that time using more colourful palettes. We discuss here



Figure 7. The pulpit before the over-paintings in 2005 (photo by Peeter Säre).



Figure 8. The sounding-board of the pulpit after the over-paintings in 2005 (photo by Jaanus Heinla, Conservation Centre "Kanut", Tallinn, Estonia).



Figure 9. The pulpit after the over-paintings in 2005 (Photo by Jaanus Heinla, Conservation Centre "Kanut", Tallinn, Estonia).

only those sample layers that give useful information for the elucidation of the history of the altar and the pulpit.

3.2.1 The lowest (original) blue layers of the altar's and pulpit's coats of arms

(Table 1: sample no 7 and Table 2, sample no 7)

The altar's coat of arms belonged to the von Derfelden's family and the pulpit's one to the von Uexkyll's family.

The analytical results indicated that the lowest blue layers of the coats of arms on the altar and the pulpit have similar chemical compositions. The blue pigment is smalt (K, Co (Al) – potash silicate with cobalt oxide). It is mixed with fillers and maybe also with a small amount of lead white ($2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$).¹⁰ Cobalt is also found in cobalt blue ($\text{CoO} \cdot \text{Al}_2\text{O}_3$) and cerulean blue ($\text{CoO} \cdot n\text{SnO}_2$).^{10,11} However, these two pigments can be excluded because the blue layers are the first layers, having been painted in the 1680s, when cerulean blue and cobalt blue were unknown. Moreover, cerulean blue can be excluded because of the absence of Sn in the EDS spectra. The discovery that smalt is the main blue pigment leads us to conclude that both coats of arms may have been made during the end of the 17th century.

3.2.2 Sculpture „Love“; two paint samples

(Table 1: samples 8, 9)

On the cross-sections it was possible to see intense greenish-blue (sample 8) and red (sample 9) mid-layers. From the windows and cross-sections could be concluded that those layers had been applied probably at the same time.

According to the SEM-EDS and ATR-FT-IR (Figure S6) analysis the two main pigments used for the greenish-blue colour were Prussian blue ($\text{Fe}_4[\text{Fe}(\text{CN})_6]_3$, characteristic absorbance at 2093 cm^{-1}) and zinc white (ZnO , strong absorption with the maximum in the range of $400\text{--}380\text{ cm}^{-1}$). Both assignments were confirmed by SEM-EDS. This paint layer could have been applied during the 1888 renovation works. However, the evidence presented above indicates that most probably in 1888 the next layers – yellow preparative and golden – were applied and it would have been unreasonable to apply them on top of the Prussian blue layer.

The colour of the red mid-layer from the lower part of the robe of the round plastic sculpture on the altar was, according to the SEM-EDS results, made using vermilion, zinc white and some fillers like chalk and maybe barium carbonate. These results indicated that the red layer was painted not earlier than in the 1840s (availability of zinc white), but could have been applied earlier than in 1888, because probably the uppermost brown layer of this sample was applied in 1888.

These results lead to the conclusion that, between the original painting of the altar and the 1888 over-painting, there had been other over-painting activities in the middle of the 19th century, that were not documented in archive materials, and that were possibly executed during the reconstruction works in 1842-45.

The pigments and repainting history of the artistic details (sculptures and coats of arms) are different from the main corpus of the altar and the pulpit. The investigations indicate that the sculptures on the altar and pulpit have not been over-painted since 1888.

3.3 History of the colour schemes

The summary of the historical and analytical studies is presented in Table 3.



Time	(Documented) action	Colour scheme after the action	Colour example	
The end of the second half of the 17 th century	Altar and pulpit were made by Christian Ackermann and by an unknown painter.	Black (charcoal black) layer covers almost the entire altar corpus and some of the altar sculptures. The remaining parts of the altar and most of the pulpit were grey. Some artistic details may have been colourful.		
1842-1845	Rebuilding of the church. Altar and pulpit were probably installed in their present location. Archive materials do not indicate over-painting.	Altar and pulpit were grey. Most sculptures were colourful.	Grey (lead white mixed with charcoal and fillers) 	
1888	Over-painting, gilding and silvering of altar and pulpit.	The altar was brown-golden. The pulpit was light-blue-brown-golden. Sculptures on the altar and pulpit had a versatile colour palette.	Altar Brown/yellow/gold (umber/chrome yellow/gold)	Pulpit Light-blue /brown/yellow/golden (ultramarine/brown ochre/chrome yellow/gold)
				
				
1927 (supposedly until 1934)	No information is available concerning the over-painting of the altar in 1927. In the period of 1927-1934 the colour scheme of the pulpit was matched with that of the altar.	The altar was not over-painted and was brown-golden. The pulpit was over-painted into brown-golden, similar to the altar. Sculptures had a versatile colour palette, just like in 1888.	Altar brown/golden (umber/chrome yellow/gold)	Pulpit brown/golden (umber/chrome yellow/gold)
				
2005	Over-painting of the altar and pulpit with oil- and alkyd paints. No over-painting of the sculptures.	The present colour scheme is shown in Figures 3, 8 and 9.		

Table 3. Colour schemes of the altar and the pulpit based on historical and chemical investigations.

4 Conclusions

Investigations revealed that the corpus of the altar had three and the corpus of the pulpit four paint layers. Although the altar and the pulpit have been made at different times, their first and second paint layers are the same and must have been applied at the same time. It was clarified that both the altar and the pulpit (including some, but not all sculptures) were grey before 1888. In the third colour layer the colour schemes of the altar and the pulpit are different. In 1888 the altar was repainted in brown-yellow-golden colour scheme while the pulpit was repainted in a different colour scheme (lightblue-lightbrown-golden) and was repainted in the same colour scheme as the altar later, during 1927-1934.

Evidence is provided that, contrary to archive documents, some over-painting of the sculptures was done between 1704 and 1888, most probably in the period 1842-1845. No over-paintings have been done on the altar since 1888 and none on the

pulpit since 1934 until the unauthorized over-painting in 2005.

It was concluded that it is not possible to remove the most recent paint layer without damaging the lower paint layers. Therefore, it was decided to leave the altar and pulpit as they currently stand and to carefully document the historic colour schemes instead.

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6 Supplementary Information

Figures S1 to S7 and Tables S1 to S8 are available as supplementary information, available from:

http://www.morana-rtd.com/e-preservation-science/2009/ePS2009_art6_SupInf_e.pdf

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