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# EVALUATION OF MEDIEVAL ESTONIAN MURALS WITH A FOCUS ON PAINTING TECHNIQUE: NOVEL FINDINGS ON PAINT LAYER COMPOSITION

## INTRODUCTION

Investigation of wall paintings is a valuable source of information that broadens our knowledge of local medieval technologies, helps to place murals in a wider regional context, and based on the comprehensive understanding of the original materials informs conservators' decisions.

The objective of the current research is, based on the analytical evidence, to better understand and analyse Estonian medieval (13th–15th century) wall-painting techniques and materials used in rural church architecture. It is the first comparative study of material analysis combined with on-site visual observation and contribute to local and regional technical art history. Eleven church sites were selected with the aim of covering the central and western regions of Estonia (historical counties of Järvamaa/Jerwen, Läänemaa/Wiek and Saaremaa/Ösel), where the most characteristic examples of medieval murals are preserved. These areas were selected based also on the accessibility and the condition of the paintings. The sample selection

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includes nine interior paintings located in Ambla, Järva-Peetri, Koeru, Türi, Martna, Ridala, Muhu, Pöide, Valjala churches and two former exterior painted decorations from the façades of Kaarma and Lüganuse churches. Since art historians and conservators have indicated, based on visual examinations, that the paintings are most probably executed in a kind of *fresco* technique, the aim has been to investigate this hypothesis using optical and electron microscopy and analytical methods to gain scientific evidence about the technique and the composition of the materials.

Estonian medieval murals have been of interest to art historians, architects and conservation specialists in the region since the beginning of the 20th century.[1] From then on paintings have been mentioned in publications by Johannes Gahlnbäck, Helge Kjellin and Villem Raam,[2] and investigation or conservation works have been carried out (at first mainly on Saaremaa). The past 20 years have brought many new findings, especially on the mainland in Järva County. Since 2004, the Department of Cultural Heritage and Conservation of the Estonian Academy of Arts (EAA) has carried out studies of church interiors, and almost each year new paintings are discovered. The current situation is that many of the paintings are preserved under the limewash layers (only fragments have been revealed during the investigation works), few are recently restored (paintings in Koeru, Pöide, Harju-Risti, Martna) and several of them have been exposed and restored in the past which means that the paintings need to be taken care of again. From the point of view of conservation issues the main problem is the overall poor condition of medieval rural churches and the lack of resources for repair and maintenance.

1 Hilkka Hiiop, Anneli Randla, "Eesti kirikute keskaegsete seinamaalingute uurimisest ja restaureerimisest" [Research and Restoration of the Medieval Murals in Estonian Churches], *Kunstiteaduslikke Uurimusi = Studies on Art and Architecture*, 18/ 3–4 (2009), 10–34.

2 Johannes Gahlnbäck, "Mittelalterliche Wandmalereien in den Kirchen zu Mohn und zu Karris auf der Insel Ösel", *Sitzungsberichte der Gesellschaft für Geschichte und Altertumskunde der Ostseeprovinzen Russlands aus dem Jahre 1913* (Riga: W. F. Häcker, 1914), 207–213; Helge Kjellin, *Die Kirche zu Karris auf Oesel und ihre Beziehungen zu Gotland* (Lund: C.W.K.Gleerup, 1928), 106–127, 232–237; Villem Raam, "Mõningaid uusi andmeid vanast dekoratiivsest seinamaalist" [Some new data on an old decorative mural painting], *Kunst,* 1 (1966), 53–56; Villem Raam, "Vanema kunsti uuematest leidudest" [More recent finds in the field of ancient art], *Kunst*, 1 (56) (1980), 49–54; Villem Raam, "Ühest vähetuntud kunstiloost Muhu saarel" [About a little-known art history on the island of Muhu], *Kunst*, 2 (64) (1984), 50–59; Villem Raam, "Valjala seinamaalidest, nende vanusest ja päritolust" [Valjala murals, their age and origin], *Kunst*, 1 (68) (1986), 59–64.



The group of conservators and art historians dealing with the subject is small. During the past fifteen years, the co-authors of this article Hiiop and Randla have published on the research and conservation of medieval murals (2009)[3]; the conservation history of medieval murals (2013)[4]; the paintings in church interiors before and after the reformation (2021)[5]; and the recent finds of church murals in Estonia (2016)[6]. In the first volume of the History of Estonian Art (2023)[7], authors (Kersti Markus, Villu Kadakas, Kaire Tooming and Anneli Randla) give a broader context to the emergence of medieval church architecture including an overview of wall paintings. Architectural historian Kaur Alttoa has devoted his research to the construction history of medieval churches and to a stylistic analysis and provenance of architectural elements, which could lead us closer to a possible attribution of the master masons.[8]

Estonian medieval wall-paintings can be divided into two main categories: architectural decoration and figurative paintings (see Figs. 1–4). Architectural paintings usually highlight architectural elements like windows, vault bosses, vaulting arches and ribs, or depict illusory windows. Traces of such decoration have been found in nearly all medieval churches where historical finishing layers have been preserved. Figurative paintings depict apostles, angels, laypersons or different creatures and symbols, and are located on the walls and vaults of the chancels and naves. These paintings are less common and are known from the churches in Valjala, Muhu,

3 Hiiop, Randla, "Eesti kirikute keskaegsete…", 9–43.

4 Anneli Randla, Hilkka Hiiop, "How Russia met Italy in Estonia. Viktor Filatov, Cesare Brandi and the conservation of medieval murals in churches on the island of Saaremaa", *Art History Supplement*, 3.2 (March 2013), 59–71.

5 Anneli Randla, Hilkka Hiiop, "Colour in church interiors, medieval and beyond", *Baltic Journal of Art History,* 21 (2021), 191–207.

6 Anneli Randla, Hilkka Hiiop, "Mõningaid uusi andmeid vanast dekoratiivsest seinamaalist" [New Finds of Church Murals in Estonia], *Kunstiteaduslikke Uurimusi = Studies on Art and Architecture*, 25/ 1–2 (2016), 139–180.

7 *Eesti kunsti ajalugu 1: 1100–1520* [History of Estonian Art, vol. 1: 1100–1520], ed. by Kersti Markus, ed.-in-chief Krista Kodres (Tallinn: Eesti Kunstiakadeemia, 2023).

8 Kaur Alttoa, *Kirikud, kabelid, kloostrid. Kirjutisi Eesti keskaegsest sakraalarhitektuurist* [Churches, chapels, monasteries. Writings on Estonian medieval sacral architecture] (Tartu: Ilmamaa, 2022); Kaur Alttoa, *Tartu: piiskopi- ja hansalinnast Emajõe Ateenaks. Kirjutisi Tartu vanemast ehitusloost* [Tartu: from bishopric and hanseatic city to Athens on the Emajõgi. Writings on Tartu's older building history] (Tartu: Ilmamaa, 2017).

Ridala, Kaarma and Karja. Paintings were certainly an integral part of the interiors and had the aim of decorating the space as well as highlighting liturgically important elements and passing on Christian teaching.[9]

Not much is known about the painters. The general perspective on attribution, by the art historians of the region, is that simple paintings were mainly executed by the master masons and not professional painters. The opinion is mostly based on the idea that murals were done soon after the vaults were finished and it was strongly connected to this construction phase.[10] The features of the simple paintings are very well known in Estonia. Master masons and skilled workers arrived here during the period of the crusades through Gotland and Riga, later local craftsmen prevailed.[11] Most probably the painters were often the master masons themselves and occasionally more experienced painters executed the work.[12]

The painted decorations are difficult to date stylistically because of their universal character over long periods, figurative murals are more specific in this respect. It is not uncommon that murals have been overpainted already during the Middle Ages due to partial rebuilding of churches, deterioration of the decoration or changing fashion and liturgy.

In many cases researchers have revealed just fragments of the paintings, and so it might be difficult to imagine the initial appearance of the medieval church interiors. Today we are very much used to the whitewashed interiors, which is often only a very recent look.[13]

9 Anneli Randla, "Seina- ja võlvimaalingud" [Wall and vault paintings], *Eesti kunsti ajalugu 1: 1100–1520* [History of Estonian Art, vol. 1: 1100–1520], ed. by Kersti Markus, ed.-in-chief Krista Kodres (Tallinn: Eesti Kunstiakadeemia, 2023), 376–381.

10 Helena Edgren, "'Primitive' Paintings: The Visual World of Populus Rusticus", *History and Images: Towards a New Iconology*, ed. by Axel Bolvig, Phillip Lindley (Turnhout: Brepols, 2003), 301–322; Katja Fält, *Wall paintings, workshops, and visual production in the medieval diocese of Turku from 1430 to 1540* (Helsinki: Suomen Muinaismuistoyhdistyksen Aikakauskirja, 2012), 32–36.

11 Kersti Markus, "Kirikute ehitamine" [Building of churches], *Eesti kunsti ajalugu 1: 1100–1520* [History of Estonian Art vol. 1: 1100–1520], ed. by Kersti Markus, ed.-in-chief Krista Kodres (Tallinn: Eesti Kunstiakadeemia, 2023), 238–241.

12 Anneli Randla, "Keila kiriku maaling – kas esimene dateeritud ja atribueeritud keskaegne seinamaaling Eestis?" [Murals in St Michael's Church in Keila – the First Dated and Attributed Medieval Wall Paintings in Estonia?], *Järelevastamine. Kaur Alttoale*, ed. by Anneli Randla (Tallinn: Eesti Kunstiakadeemia, 2017), 263–272.

13 Randla, Hiiop, "Colour in church interiors…", 191–207. In several cases medieval murals have been overpainted with colourful post-Reformation decorations up until the 19th century. These later wall-paintings are not discussed in this article.



FIGS. 1–4. FRAGMENT OF FIGURATIVE PAINTINGS IN THE CHANCEL OF RIDALA CHURCH; ARCHITECTURAL PAINTINGS IN THE CHANCEL OF MARTNA CHURCH; VAULT PAINTINGS IN THE NAVE OF PÖIDE CHURCH; ARCHITECTURAL PAINTINGS IN KOERU CHURCH. PHOTOS: PEETER SÄRE

Together with polychrome altarpieces, wood and stone carvings, a baptismal font, stained glass windows and other elements of medieval Catholic interiors, wall paintings added to the vibrant and colourful look. Koeru's Mary Magdalene Church, with its recently uncovered and extremely well preserved wall paintings is a good example.

## SAMPLING AND METHODS

Samples of interior and exterior paintings were collected during conservation work or during investigations carried out from 2019 to 2024. Microstratigraphic samples were carefully collected from the decorated vaults and walls where the medieval render was still preserved and untouched by conservation work (except the Valjala figurative paintings[14]) (Table 1). Samples were initially embedded into a transparent light curing resin (Technovit 2000 LC). Polished cross sections were prepared and examined under the optical microscope (Olympus BX53M) in reflected and UV light. Scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS) were combined to contribute to the determination of painting techniques (true *fresco*, lime *fresco*, *secco* or the combination of techniques) and the composition of the ground plaster, limewash and paint layers. For this purpose, cross sections were studied using the ZEISS EVO MA15 scanning electron microscope.[15] Samples were inspected in a variable pressure mode and images were captured with the backscattered electron detector. Qualitative and quantitative elemental composition was carried out using SEM-EDS analysis with the Oxford AZTEC-MAX energy-dispersive detector using AZtecEnergy acquisition and EDS analysis software.

In addition, microchemical spot tests of the paint layers were carried out to determine the content of organic binding media (specifically content of proteins) using a test for the presence of pyrrole derivatives (samples from Ambla, Koeru, Järva-Peetri, Ridala, Pöide and Valjala). Three paint layer samples, originating from Pöide, Koeru and Ambla churches, were additionally analysed using the gas chromatography mass spectrometry (GC-MS) to determine the type of organic binder used in the paints.[16] The procedure for the analysis was based on an acidic hydrolysis of proteins to liberate amino acids, followed by the derivatization and quantitative determination of amino acids as their silyl derivatives. The GC-MS analyses were

14 Figurative paintings in Valjala church have been restored by Viktor Filatov in the beginning of the 1970s.

15 The SEM-EDS device was used in courtesy of the Department of Geology, University of Tartu, with the assistance of MSc. Marian Külaviir and PhD. Assoc. Prof. Signe Vahur.

16 Analysis carried out by Dr. MSc. Václav Pitthard, Kunsthistorisches Museum, Vienna.



performed on a 6890N gas chromatograph connected to a quadrupole mass spectrometer, model 5973N (both Agilent Technologies, USA).

Results are also drawn from the paint layer investigation reports of the EAA field works. Visual observations were mainly made using the raking light method to determine the presence of incision lines and toolmarks, as well as to detect the general morphology of the lime-washed and painted surfaces.

**Table 1.** Overview of the collected stratigraphy samples.

| Sample ID | Type | Dating | Painting style | Sampling location | Stratigraphy | OP microscopy image (mag. 100x) |
|---|---|---|---|---|---|---|
| **INTERIOR PAINTINGS** | | | | | | |
| Koeru1_red | Cross section | 13th c | architectural | 3rd vault in the nave; SW corner | 3. painting<br>2. limewash<br>1. plaster |  |
| Koeru2_red | Cross section | 15th c | architectural | 3rd vault in the nave; from the SE groin | 3. thin remain of limewash<br>2. painting<br>1. plaster |  |
| Koeru2_grey | Cross section | 15th c | architectural | 3rd vault in the nave; from the N side of the N transversal arch | 3. thin remain of limewash<br>2. painting<br>1. plaster |  |
| Ambla_red | Cross section | 13th c? | architectural | E wall in the nave, from the right side | 4. remain of top limewash<br>3. red paint<br>2. limewash<br>1. plaster |  |
| Ambla_black | Not prepared | 13th c? | architectural | From the triumphal arch (on the E side) | Sample from black paint layer only | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| J-Peetri_red | Cross section | 13th c | architectural | W wall in the nave; from the right side | 2. red paint<br>1. limewash |  |
| Türi_red | Cross section | 13th c | architectural | Vaulting panel in the chancel | 3. painting<br>2. limewash<br>1. plaster |  |
| Martna2_red | Cross section | 15th / 16th c | architectural | NW groin in the chancel; two layers of paintings | 4. painting<br>3. limewash<br>2. painting<br>1. limewash |  |
| Ridala_red | Cross section | 13th c | figurative | W wall in the nave; lower part on the right side | 4. remain of top limewash<br>3. red paint<br>2. limewash<br>1. plaster |  |
| Muhu_red | Cross section | 13th c | architectural / figurative | W wall in the nave; from the painting fragment located in the middle of the wall | 3. painting<br>2. limewash<br>1. plaster |  |
| Pöide_red | Cross section | 13th c | architectural | S wall arch of the third vault in the nave | 3. painting<br>2. limewash<br>1. plaster |  |
| Valjala_apostel | Cross section | 13th c | figurative | N wall in the chancel; from the rightmost figure. | 3. painting<br>2. limewash<br>1. plaster |  |
| Valjala_red | Cross section | 13th c | architectural | 3rd vault in the nave, W arch rib | 3. painting<br>2. limewash<br>1. plaster |  |



| | | | | | | |
|---|---|---|---|---|---|---|
| Valjala_grey | Cross section | 13th c | architectural | 3rd vault in the nave, W arch rib | 3. painting<br>2. limewash<br>1. plaster |  |
| **EXTERIOR PAINTINGS** | | | | | | |
| Lüganuse_red | Cross section | 13th c | Painted decoration –cross and inscription | W façade | 2. painting<br>1. plaster |  |
| Lüganuse_black | Cross section | 13th c | Painted decoration –cross and inscription | E façade | 2. painting<br>1. plaster |  |
| Kaarma_red | Cross section | 13th c | Frieze decoration under the cornice | N façade | 2. painting<br>1. plaster |  |
| Kaarma_grey | Cross section | 13th c | Frieze decoration under the cornice | N façade | 2. painting<br>1. plaster |  |

## *FRESCO* OR *SECCO*?

The wall paintings examined in this study are mainly architectural decorations, most probably painted by the master masons or trained painters. Often the question has been whether the paintings were made in true *fresco,* lime *fresco* or *secco* technique, or a combination of both. True *fresco* means that murals were painted on fresh plaster and the pigments are bound with the calcium hydroxide present in the ground plaster or limewash, and fixed by the carbonation process. Pigments are mixed with water, lime water or with additional organic

binding media, such as casein.[17] The technique is well known for its durability and specific identification features visible on closer observation. These features, such as *giornate* (day work), *pontate* (work at the limits of the scaffolding floor) and incisions are often used as first references to determine the painting technique. The term 'lime *fresco*' (also called *mezzo fresco*) refers to a technique where pigment is mixed with lime milk before application.

In the *secco* technique pigments are first mixed with a binding medium and then applied to a dry wall. This can be a lime milk, lime putty or organic binder. When using a lime binder the surface is pre-wetted to adhere better.[18]

In Western medieval tradition the preparation of the wall paintings started from the application of the two layers of the preparatory ground – *arriccio* (coarse) and *intonaco* (fine). Preparatory drawings were marked on *arriccio* to sketch more complicated figurative schemes (so called *sinopia*), incised into fresh *intonaco* or transferred using other methods like *spolvero*. Craftsmen who decorated Estonian medieval church interiors were familiar with at least some of the preparatory techniques. For example, incisions have commonly been used to sketch the architectural elements in almost all the studied sites, both in interiors and exteriors.

Based on few technical studies published in English, similarities can be drawn between the medieval painting techniques in the region of the Baltic sea. Byzantine and early Gothic style paintings preserved in Gundsømagle Church, Denmark are painted on the limewash using lime based paint or organic binders. Lime white is used as pigment but most probably also as a binder in Byzantine style paintings on the island of Gotland (Sweden).[19] Recent research about the murals in the Castle of Riga, Latvia refer to the combined *fresco* technique – mixture of pigment and water has been soaked into

17 Paolo Mora, Laura Mora, Paul Philippot, *Conservation of Wall Paintings* (London: Butterworths, 1984), 11–12.

18 Mora, Mora, Philippot, *Conservation of Wall Paintings*, 12–13.

19 Tim Padfield, Peder Bøllingtoft, Bent Eshøj, Mads Chr. Christensen, "The wall paintings of Gundsømagle church, Denmark", *Studies in Conservation*, 39/sup2 (1994), 94–98; Peder Bollingtoft, Mads Chr. Christensen, "Early Gothic wall paintings: an investigation of painting techniques and materials of 13th-century mural paintings in a Danish village church", *ICOM Committee for Conservation tenth triennial meeting, Washington, DC, 22-27 August 1993: preprints*, 2 (Washington: ICOM, 1993), 533; Anders G. Nord, Kate Tronner, Kjell Billström, Birgitta Strandberg Zerpe, "Analysis of mediaeval Swedish paintings influenced by Russian-Byzantine art", *Journal of Cultural Heritage*, 23 (2017), 162–169.



the fresh limewash and in some areas combined with protein *secco*.[20] Art historian Katja Fält suggests that in Finland the late medieval paintings were usually painted on dry plaster *a secco*, and sometimes on semi-dry ground. Simple clay earth pigments and powdered charcoal were mixed with lime and used on the thin layer of ground limewash.[21] At the moment information about the painting techniques and used materials in the region is fragmented. Hopefully there will be much closer future collaborations on the subject to be able to make broader conclusions.

On the visual examinations it is clear that Estonian interior paintings are mostly executed in lime on the limewash ground. Even then it is not unambiguous if Estonian paintings are prepared in true *fresco*, lime *fresco* or lime *secco* technique. To better answer that question, micro-stratigraphic cross sections of the historic and for the comparison new experimental paintings were studied under optical and scanning electron microscopes. This was done with the aim of observing the connection between different layers, and ascertaining whether the calcium carbonate rich thin film had been formed on the surface of the limewash or the ground plaster before paint was applied. According to analytical literature the presence of the carbonated layer can be an indicator of the dryness of the ground surfaces during the painting processes, thus pointing to *secco*; however, the same effect can also occur in *fresco* technique, if executed during the early carbonation process of the ground.[22]

The same questions remain when studying façade paintings. Due to exterior climate conditions, only a few examples or traces of façade decoration have been preserved (see Figs. 5–6). One of the objectives has been to understand if and how exterior paintings differ from the interior ones.

20 Madara Rasiņa, Ojārs Spārītis, Jiřina Přikrylová, Martin Racek, Ivana Kopecká, Eva Svobodová, Richard Přikryl, "The recent discovery, research, and restoration of medieval and renaissance frescoes in Riga Castle—A treasure to the Baltic region", *Heritage*, 6/3 (2023), 2441–2444.

21 Fält, *Wall paintings, workshops, and visual production in the medieval diocese of Turku from 1430 to 1540*, 170–172.

22 Lucia Regazzoni, Giovanni Cavallo, Danilo Biondelli, Jacopo Gilardi, "Microscopic analysis of wall painting techniques: Laboratory replicas and romanesque case studies in Southern Switzerland", *Studies in Conservation*, 63/6 (2018), 326–341.

FIGS. 5–6. FORMER EXTERIOR DECORATIONS ON THE N-FAÇADE OF KAARMA CHURCH (CURRENTLY HIDDEN BEHIND LATER CONSTRUCTION); FORMER EXTERIOR INSCRIPTIONS AND CROSS ON THE W-FAÇADE OF LÜGANUSE CHURCH (CURRENTLY VISIBLE IN THE TOWER). PHOTOS: PEETER SÄRE



## VISUAL OBSERVATIONS

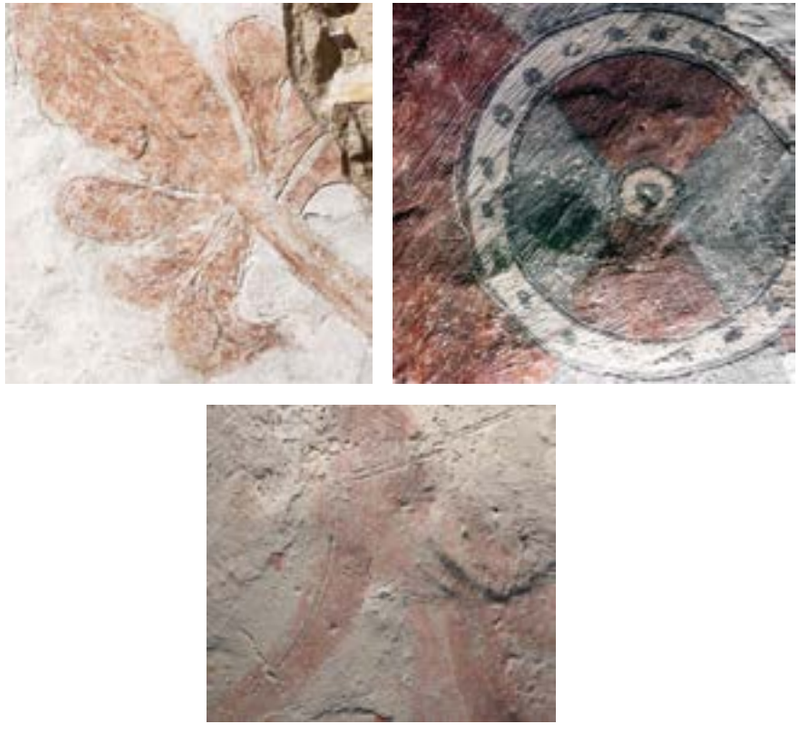
During visual observations, mainly the morphology of the painted surfaces, thickness and the amount of preparatory plaster layers (if possible) and the stylistic features of the paintings were recorded. It is characteristic of the Estonian medieval interior plasters to have an uneven surface that follows the masonry. It was possibly worked over with a trowel or wooden float, but the information about the finishing techniques is poor because the toolmarks and *pontate* (work at the limits of the scaffolding floor) are hidden under the limewash layers. The thickness of the ground plaster was best observed during the conservation work in the western vault in Pöide church. There, plaster has been applied in a single layer with a thickness varying from about 1 to 5 cm. In all cases plaster was used to shape the groins, and in the case of Pöide also the boss in the centre of the western vault.

Incisions are helpful when constructing the compositions of architectural paintings on large scale especially when outlining rose windows, bosses with groins and inscriptions. Sometimes incisions were marked free hand, in other cases additional tools such as compass or a straight board have been used to construct more complicated geometry (Figs. 7–9). These markings in fresh plaster or limewash were observed at all of the selected sites, except in Ambla and Järva-Peetri. It means that the painters had started planning the composition while the plaster was still wet. In the case of figurative paintings, incisions were noticed only in Ridala where thin lines had been sketched in fresh limewash to construct the pattern of cloth folding. Other elements of the figures such as hands, heads, etc., were executed in freehand drawing. This is definitely a sign of more experienced masters who were used to sketching figures.

Another method known to have been used by medieval painters is stencil.[23] This was used to repeat the pattern of ornaments as it has been observed in Koeru and Keila churches.[24] Stencils could also have been used to transfer more complicated parts of figurative paintings like faces, hands and feet. Although this aspect needs

23 Roger Rosewell, *Medieval Wall Paintings* (Woodbridge: The Boydell Press, 2008), 121–132; Fält, *Wall Paintings, Workshops, and Visual Production in the Medieval Diocese of Turku from 1430 to 1540*, 171–173.

24 Randla, Hiiop, "Mõningaid uusi …", 154; Randla, Hiiop, "Colour in church interiors…", 197.



FIGS. 7–9. EXAMPLES OF INCISIONS IN PLASTER. FROM THE LEFT: FREEHAND INCISIONS ON A FRAGMENT OF THE PAINTINGS LOCATED IN ST MARY'S CHURCH, PÖIDE. PHOTO: PEETER SÄRE, 2012; COMPASS INCISIONS ON A FRAGMENT OF THE PAINTINGS LOCATED IN KOERU'S MARY MAGDALENE CHURCH. PHOTO: PEETER SÄRE, 2018; AND COMPASS INCISIONS ON A FRAGMENT OF THE VAULT PAINTING IN ST MARTIN'S CHURCH IN TÜRI. PHOTO: R. K. RANDLA, 2024

further investigation, it could explain the lack of incisions in case of the figurative paintings.

The colour palette of the paintings is simple. Black and red pigments are commonly used for architectural paintings. Lime white is used in mixtures to achieve the different variations of the black and red colours. Sometimes a bluish shade of grey is achieved by mixing charcoal black with lime white (best visible in Koeru church). Figurative schemes are usually painted in strong red with the addition of black or grey and yellow (for example, Muhu). In Ridala red and yellow pigments were used.



## ANALYTICAL RESULTS

Optical (PLM) and scanning electron microscope (SEM) observations and energy dispersive X-ray spectroscopy (EDS) analyses were carried out to distinguish between *fresco* and *secco* painting techniques, to understand the material composition and to map the elemental distribution in the painted plaster stratigraphy with the aim of detecting where the carbonation film has formed. This method has been used before for similar research, a recent study is published by Lucia Regazzoni *et al*.[25] Therefore the appearance of the interface between the plaster, lime-wash and the paint layers were observed, especially the connection between the paint and the ground. According to Regazzoni *et al*. we can say that the presence or absence of a calcium carbonate rich layer is one of the criteria to identify *secco* and *fresco* paintings. If the calcium rich layer is absent between the paint and the ground, the paint has penetrated into the ground, and a thin layer is present on the surface of the paint layer, then this is an indication of *fresco.* If the calcium rich layer is present between the support and the pictorial layer then this is an indicator of either *fresco* or *secco* technique. The calcium rich layer can form in the very early stages of the carbonation process (according to Regazzoni *et al*. from one hour) making it possible to execute *fresco* painting when the plaster has already started to set.[26] The time of setting can vary considerably depending on many aspects such as the type of masonry, amount of water in the mortar or limewash, thickness of the applied layers, weather conditions and indoor environment.

Based on previously described knowledge, elemental maps, backscattered electron (BSE) images and PLM images from all the micro stratigraphic samples were observed to make conclusions and set hypotheses about the painting techniques. All the studied interior murals are painted on limewash except exterior decorations in Kaarma and Lüganuse. Surprisingly the limewash layer was not detected on the cross sections prepared from Koeru's 15th century paintings, even though it is visible on the site. This can be partly explained with the sampling location (see Table 1) and the possible uneven whitewashing of the ground plaster.

25 Regazzoni, Cavallo, Biondelli, Gilardi, "Microscopic analysis …", 326–341.

26 Ibid., 334.

Calcium carbonate rich interface was detected between the plaster and limewash layers in all paintings that had a preparatory limewash layer. Based on the presence or absence of the calcium-rich layer between the ground and paint layer, paintings were specified as true *fresco*, lime *fresco* or lime *secco*. In this specific case lime *fresco* and *secco* means that lime binder (diluted lime putty or lime water) or additional organic binding media (for example casein) is used (see in more detail in Table 3). Observations and analysis show that paintings from Koeru (both 13th and 15th century), Türi, Martna (1st layer) and Valjala (architectural) contain lime as a binder. In the rest of the paintings we do not know if just water, lime water or lime milk was used. It is also possible that just organic binding media or its mixture with lime based binder was used.

To determine the presence of organic binding media and possible protein content in the paint layers, microchemical spot tests for the pyrrole derivatives were carried out. Based on these results three samples were selected for the GC-MS analysis to determine the type of organic binder (see the result in Table 2). Two of them gave results. The novel finding about the composition of the lime based paint was the organic additives. The results of the GC-MS carried out for the paint layers from Ambla (13th century?) and Koeru (15th century) show the presence of a series of amino acids, most probably casein. This means that lime casein paint was used. Traditionally such paint is made by adding skimmed milk to lime.[27] From the third analysed sample (Pöide 13th century red) the result was not gained due to the lack or only very small amount of organic binder preserved in the paint.

The content of different oxides was measured in the plaster and limewash layers of the samples to determine the composition of lime. According to the results the samples could be divided into three groups: calcitic (Lüganuse, Valjala figurative), weakly dolomitic (Ambla, Järva-Peetri, Türi, Ridala, Martna, Muhu) and dolomitic (Koeru, Pöide, Valjala architectural, Kaarma) limes (Table 4). This distribution is in correlation with the composition of local limestone

27 Francesca Casadio, Ivana Giangualano, Francesca Piqué, "Organic materials in wall paintings: the historical and analytical literature", *Studies in Conservation*, 49/sup1 (2004), 67.



found in the vicinity of the sites.[28] All the ground plasters were prepared from local silica sand.

Analytical results confirmed that red ochres and charcoal black pigments have been used to tone the paints. An exception is Valjala figurative paintings where lead red is used.

**Table 2.** Results of the microchemical spot test to determine the content of protein and the results of GC-MS analysis to determine the type of protein.

| Sample | Dating | Spot test (content of protein) | GC-MS[29] (type of protein) |
|---|---|---|---|
| Ambla_black | 13th c? | (+/-) | A series of amino acids (protein = casein?) |
| Koeru1_red | 13th c | + | Not analysed |
| Koeru2_red | 15th c | + | A series of amino acids (protein = casein?) |
| Koeru2_grey | 15th c | + | Not analysed |
| J-Peetri_red | 13th c? | + | Not analysed |
| Ridala_red | 13th c | (+/-) | Not analysed |
| Pöide_red | 13th c | (+/-) | Analysed, but no result |
| Valjala_grey | 13th c | - | Not analysed |

28 *Maa-ameti geoloogiline aluspõhja kaart* [Estonian Land Board's map application for geological bedrocks], available online: https://xgis.maaamet.ee/xgis2/page/link/pXS1JSP5 [accessed January 24, 2025].

29 Václav Pitthard, internal report of the Kunsthistorisches Museum Wien, 2024.

**Table 3.** Conclusions on material composition and wall painting techniques.

| Sample ID | Ground plaster composition | Lime wash composition | Paint layer composition | Approx. paint layer thickness (µm) | Ca-rich interface on ground | Ca-rich interface on lime wash | Ca-rich veil on paint layer | Incisions | Notes and hypothesis on painting technique |
|---|---|---|---|---|---|---|---|---|---|
| Ambla | Weakly dolomitic lime, silica sand | Weakly dolomitic lime | Red ochre | 18,27–46,20 | Yes | Yes? | No | No | Thin layer of paint on limewash. Very thin Ca-rich veil visible on the limewash which can refer to secco or fresco on semi dry limewash ground. |
| J-Peetri | Weakly dolomitic lime, silica sand | Weakly dolomitic lime | Red ochre | 7,87–22,40 | - | No | Yes | No | Very thin layer of paint on limewash. Pigment penetrated into the limewash and the Ca-rich veil has formed on top – possibly referring to fresco painting on limewash ground. |
| Koeru_13c | Dolomitic lime, silica sand | Dolomitic lime | Red ochre mixed with dolomitic lime. Protein content. | 39,68–89,61 | Yes | Yes | Yes | Yes – in lime wash | Paint is dispersed into the second very thin layer of limewash referring to fresco technique. Sharp Ca-rich veil is visible on top of the 1st and 2nd limewash layer. |
| Koeru_15c | Dolomitic lime, silica sand | No lime wash layer recorder on the cross section but visually present on the site | Red ochre mixed with (dolomitic) lime-casein. | 67,23–120 | Yes | - | Yes | Yes – in ground plaster | Thicker layer of lime-casein paint applied directly on the ground plaster. Ca-rich layer was detected on the ground referring to secco or lime fresco on semi dry ground. |
| Koeru_15c | Dolomitic lime, silica sand | No lime wash layer recorded on the cross section. | Charcoal black mixed with lime-casein. | All paint is dispersed into the ground – 84,49–135,69 µm deep | No | - | Yes | Yes – in ground plaster | Finely grind pigment has dispersed into the ground plaster and a Ca-rich layer has formed on top referring to fresco technique. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Türi | Weakly dolomitic lime, silica sand | Weakly dolomitic lime | Red ochre mixed with dolomitic lime | 53,79–58,62 | Yes | Yes | Yes? | Yes – in ground plaster | Thicker layer of paint is applied on limewash ground. A slight Ca-rich layer has formed on top of the limewash referring to secco or lime fresco on semi dry ground. |
| Ridala | Weakly dolomitic lime, silica sand | Weakly dolomitic lime | Red ochre | All paint is penetrated into the ground –19,69–97,69 µm deep | Yes | | Yes | Yes – in lime wash layer | Thin layer of pigment has penetrated into the limewash ground. Ca-rich layer has formed on top of the paintings referring to a fresco technique. |
| Martna 1st layer | Weakly dolomitic lime, silica sand | Weakly dolomitic lime | Red ochre mixed with calcitic lime | 48,61–149,48 | Yes | Yes | Yes | Yes? | Lime paint which contains roughly grind pigment is applied on the limewash ground. Ca-rich layer has formed on top of the ground – referring to secco or lime fresco on semi dry ground. |
| Martna 2nd layer | - | Calcitic lime. | Red ochre | 12,15–25,55 | - | No | Yes | Yes | Two layers of limewash underneath the paint. Thin layer of paint is dispersed into the top layer of ground limewash referring to fresco technique on lime ground. |
| Muhu | Weakly dolomitic lime, silica sand | Weakly dolomitic lime | Red ochre | 4,99–6,05 | Yes | Yes | Yes? | No | Very thin layer of paint on the limewash ground. Paint layer seems to be bound with the Ca-rich layer on top of the ground limewash referring to the fresco technique. |
| Pöide | Dolomitic lime, silica sand | Dolomitic lime | Red ochre | 44,20–108,48 | Yes | Yes – only on the first layer of lime wash. | No | Yes – in ground plaster | Two layers of limewash on the ground plaster. Pigment is penetrated into the second layer of limewash referring to fresco technique. |

| | | | | |
|---|---|---|---|---|
| Valjala architectural | Dolomitic lime, silica sand | Dolomitic lime | Red ochre mixed with dolomitic lime | 43,24–107,65 |
| Valjala figurative | Calcitic lime, silica sand | Calcitic lime | Pb red pigment – altered to black. | All paint is penetrated into the ground – 65,63–131,26 μm deep |
| **EXTERIOR PAINTINGS** | | | | |
| Kaarma | Dolomitic lime, silica sand | - | Red ochre | 102,58–158,75 |
| Kaarma | Dolomitic lime, silica sand | - | Charcoal black | 21,99–94,58 |
| Lüganuse | Calcitic lime, silica sand | - | Red ochre | All paint is penetrated into the ground – 122,14–317,50 μm deep |
| Lüganuse | Calcitic lime, silica sand | - | Charcoal black | All paint is penetrated into the ground |



| | | | | |
|---|---|---|---|---|
| Yes | Yes | ? | ? | Lime paint is applied on the ground limewash. Most probably the paint is applied on the dry or semi dry ground referring to secco or lime fresco technique. |
| Yes | - | Yes | No | Sample was collected from pictorial not preparatory layer with underdrawings. Painted on the limewash ground. Pigment has penetrated into the limewash. |
| | | | | |
| Yes | - | No | Yes – in ground plaster | Paint is applied directly on the smoothened ground plaster. Ca-rich interface under the paint layer is referring to the fresco or lime fresco on semi dry ground. Due to this fact red seems to be applied some time later than gray paint. |
| - | - | Yes | Yes – in ground plaster | Paint is applied directly on the smoothened ground plaster. Pigment is well bound in the Ca-rich layer on top of the surface referring to the fresco or lime fresco on fresh ground. |
| No | - | No | Yes – in ground plaster | Paint is applied directly on the fresh plaster (fresco). Pigment has penetrated into the ground and no Ca-rich interface is visible. |
| No | - | No | Yes – in ground plaster | Paint is applied directly on the fresh plaster (fresco). Pigment has penetrated into the ground and no Ca-rich interface is visible. |

**Table 4.** Results of EDS analysis for the content (Mass %) of oxides in the lime matrix of ground plaster (abbreviation pl) and limewash (abbreviation lw) layers.

| Sample ID | CaO | MgO | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $K_2O$ | $Na_2O$ | $SO_3$ |
|---|---|---|---|---|---|---|---|---|
| Ambla_pl | 48.46 | 28.97 | 11.14 | 5.80 | 2.76 | 1.81 | - | 1.05 |
| Ambla_lw | 60.27 | 15.41 | 9.82 | 7.77 | 1.75 | 3.00 | - | 1.98 |
| J-Peetri_pl | 60.23 | 37.81 | 0.84 | - | 1.12 | - | - | - |
| J-Peetri_lw | 60.95 | 26.07 | 3.48 | 6.91 | 1.96 | 0.63 | - | - |
| Koeru_13c_pl | 51.34 | 26.93 | 10.02 | 6.60 | 1.57 | 0.66 | 1.75 | 0.34 |
| Koeru_13c_lw | 43.63 | 44.62 | 5.06 | 3.18 | 0.62 | 0.43 | 1.40 | 0.37 |
| Koeru_15c_pl | 43.20 | 26.01 | 7.80 | 17.31 | 0.84 | 0.72 | 0.85 | 2.35 |
| Türi_pl | 38.04 | 47.77 | 8.69 | 3.36 | - | 2.15 | - | - |
| Türi_lw | 60.50 | 26.03 | 8.10 | 2.63 | 1.11 | 1.63 | - | - |
| Ridala_pl | 68.62 | 14.98 | 7.60 | 2.26 | 2.84 | 1.20 | 1.67 | 0.83 |
| Ridala_lw | 79.58 | 7.22 | 9.36 | 0.85 | 1.10 | 0.71 | - | 1.18 |
| Martna_1st_pl | 66.17 | 18.74 | 8.44 | 2.36 | 1.63 | 2.67 | - | - |
| Martna_1st_lw | 77.80 | 13.02 | 6.10 | - | - | 3.07 | - | - |
| Martna_2nd_lw | 77.46 | 4.47 | 8.44 | 5.31 | 2.35 | 1.98 | - | - |
| Muhu_pl | 53.70 | 20.24 | 9.19 | 11.19 | 3.35 | 1.31 | - | 1.02 |
| Muhu_lw | 64.66 | 20.83 | 6.45 | 2.71 | 3.67 | 0.93 | - | 0.74 |
| Valjala_fig._pl | 85.46 | 10.07 | 2.36 | 1.11 | - | 1.00 | - | - |
| Valjala_fig._lw | 75.67 | 18.98 | 4.02 | 1.33 | - | - | - | - |
| Valjala_pl | 49.88 | 22.44 | 6.18 | 11.12 | 1.21 | 1.64 | 1.15 | 4.99 |
| Valjala_lw | 47.68 | 28.54 | 7.84 | 11.39 | 0.71 | 0.69 | 1.00 | 1.51 |
| Pöide_pl | 31.20 | 49.32 | 11.21 | 5.03 | 0.61 | 0.64 | 0.82 | 0.71 |
| Pöide_lw | 47.87 | 32,.67 | 3.24 | 14.19 | 0.19 | 0.27 | 0.60 | 0.66 |
| Kaarma_pl | 31.73 | 35.16 | 23.03 | 7.31 | 1.98 | - | - | 0.79 |
| Lügan._grey_pl | 71.68 | 2.22 | 16.00 | 4.16 | 3.02 | 1.92 | - | 0.99 |
| Lügan._red_pl | 48.03 | 20,34 | 19.06 | 2.93 | 8.74 | 0.89 | - | - |



## EXPERIMENTING WITH PAINTING TECHNIQUES

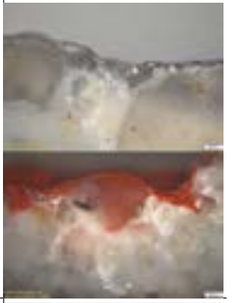
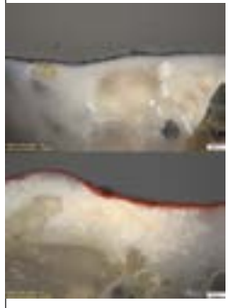
The research process included experimenting with different paint compositions and application timings (Table 5; Figs. 10–11). The aim was not to create exact copies of the medieval murals, but to better understand empirically the process of painting on wet and semi-dry plaster. Further goals were to observe the stratigraphic samples of *fresco* and *secco* painting techniques on a microscopic level, as well as to compare the results gained from the historic samples to similar research published in the field (mainly Regazzoni *et al*. and Pieovesan *et al*.).[30] We must mention that only initial experiments were performed with the objective of differentiating between *fresco* and *secco* applications, with pigments mixed with pure water and diluted lime paste. In future research this can be done with more precision and a focus on exact replication. Experimental paintings were prepared on a lime plaster ground using iron oxide red (a commercial product) and charcoal black (made from charcoal of coniferous wood which was collected during a lime burning workshop) pigments. The ground was prepared from local lime that had been burned in an experimental kiln during a lime burning workshop in Lümanda, Saaremaa[31]. A lime rich hot mixed mortar with the ratios of one part of CaO to two parts silica sand (0–2 mm) was applied to a pre-wetted clay tile (5 mm thick) after one hour of mortar preparation. A 2 cm thickness of mortar was applied and the surface was dressed with a trowel (experiments 3.1, 3.2 and 8). A second tile covered with lime plaster was used as a completely dry ground prepared at least 12 months earlier with a commercial lime mortar (experiments 15 and 20). In addition to the experiments with lime, lime casein paint was prepared from lime paste and skimmed milk. The aim was to evaluate the effect of casein on the working properties of the paint and if any visual differences occur. For comparison of the lime and lime casein paint properties two mixtures with the same amount of liquid and lime were prepared (20 ml of water or skimmed milk + 20 ml of lime putty).

Applications of the paint layers are presented in the following table:

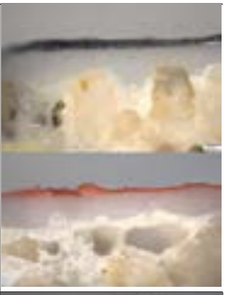
30 Regazzoni, *et al*., "Microscopic analysis …", 326–341; Rebecca Piovesan, Claudio Mazzoli, Lara Maritan, Paolo Cornale, "Fresco and lime-paint: an experimental study and objective criteria for distinguishing between these painting techniques", *Archaeometry,* 54/4 (2012), 723–736.

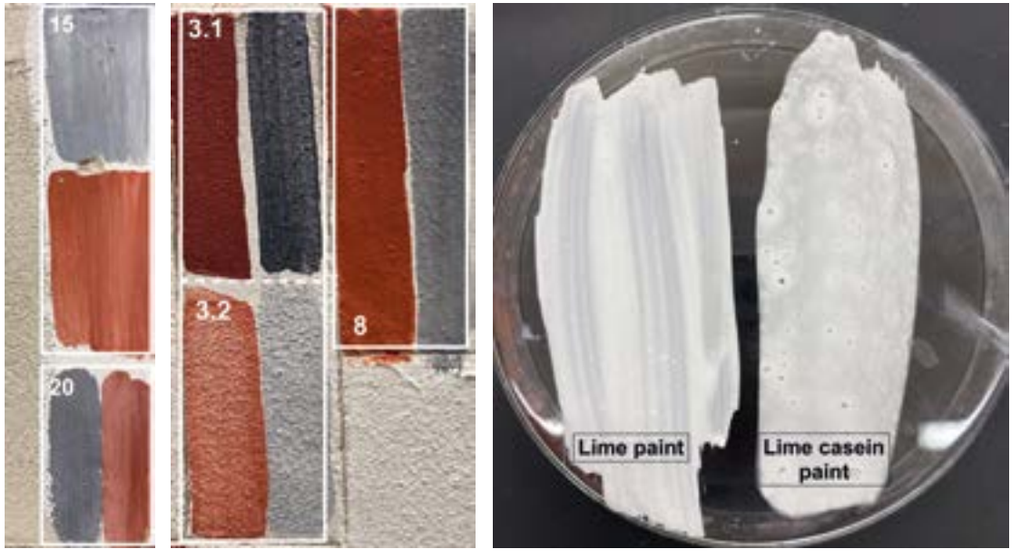
31 Held in Lümanda Lime Park, Saaremaa, Estonia in August, 2024.

**Table 5.** Overview of the experiments.

| No. of experiment | Time of application | Description | Notes | OP microscope images of cross sections (mag 100x) |
|---|---|---|---|---|
| 3.1 –true *fresco* | 1 hour after plaster application | Charcoal black and iron red pigments were mixed with water and applied to the plaster. | Plaster is moist and soft and the paint must be applied carefully. |  |
| 3.2 – lime *fresco* | 1 hour after plaster application | Charcoal black and iron red pigments were mixed with $Ca(OH)_2$ and applied to the plaster. | Plaster is moist and soft and the paint must be applied carefully. |  |
| 8 – lime *fresco* | 3h 30 min after plaster application | A layer of limewash was applied to the plaster. The limewash was prepared about 20 min before the application, slaked from the darker white CaO – originating and burned in Lümanda. | Plaster is almost hardened. |  |
| | 22 h after plaster application | Black and red lime paint was applied to the previously limewashed surface. | Ground layers were hardened but moist. It was good / comfortable to apply the paint to the surface. No prewetting was necessary. | - |



| | | | | |
|---|---|---|---|---|
| 15 – lime *secco* | Applied to at least 12 month old plaster ground | Limewash was applied on a prewetted plaster. After 20 minutes red and black lime paint was applied on the semidry whitewash. | Comfortable to apply the paint to a thin and a somewhat transparent layer. |  |
| 20 – lime casein *secco* | Applied on at least 12 months old plaster ground | Applied on a dry limewash and pre-wetted surface. | No difference in the feeling of application compared to pure lime paint. |  |




FIGS. 10–11. ON THE LEFT: PLASTER PANELS WITH EXPERIMENTS. ON THE RIGHT: LIME AND LIME CASEIN PAINT BRUSHED ON THE PETRI DISH. IMAGES: VARJE ÕUNAPUU, 2024

As a result of the experiments the following conclusions can be drawn:

- Application of the paint to fresh and still soft plaster was difficult because it was easy to mix the paint with the soft ground by accident when brushing it on the surface. To be able to paint comfortably, the surface needs to be cured to some extent to be a strong enough support while painting.
- The most comfortable application was experiment 8 where the ground had become solid but the surface was still moist, meaning that pre-wetting was not necessary.
- Lime casein paint was more liquid than lime paint containing the same amount of added liquid, meaning that casein changes the properties of the paint (Fig. 11).
- Organic additives create air bubbles in lime casein mixture which are visible also in dry layers (Fig. 11).

## DISCUSSION AND CONCLUSIONS

The main objective of the current study was to contribute to the topic with analytical information about the material composition and with better understanding of local medieval wall painting techniques. Based on the microscopic analysis of the collected samples we were able to confirm some of the features visible on the sites but also to gain additional information. Stratigraphy of the ground layers, morphological features and thickness of the paint layers were recorded to clarify the painting techniques. Additionally, initial information about the paint layer composition was gained, which was later specified with the chemical analysis for the selected samples. It has to be mentioned that there are some limitations to the microscopy method which need to be taken into account. First of all the samples are small and we are observing only a small fraction of the area meaning that it is not necessarily the most characteristic sample from the paintings. Which means that the information definitely needs to be combined with the knowledge gained from the visual observations on the sites and the broader knowledge about the local and regional traditions. Interpretation of the historic samples can be sometimes misleading and unclear due to the poor condition of the paintings. For example, the surface of the paint layer can be damaged or partly lost and this can influence the interpretation. The chosen



methods definitely require a higher number of studied samples to be able to make broader conclusions. Current study is the starting point of that approach and hopefully there will be ongoing research which can add to the knowledge gained so far.

The common knowledge about the local medieval wall painting techniques has evolved based on the *in situ* observations through different research and conservation actions through the years. We know that to prepare architectural paintings on large surfaces, medieval master masons first plastered the walls and vaults, then incisions were drawn into the fresh or semi-dry ground to sketch the design. It is assumed that the painter was already present in that stage to prepare the sketches. Limewash was brushed on the plaster to prepare the ground for painting. It is clear that these steps were taken prior to painting which means that some areas of the ground could be more cured than others. The level of humidity must have been high in the interiors throughout that process and the surfaces were most probably still moist when the paintings were executed. If the painters were deliberately using these conditions to create frescoes remains a question? Experimenting with the painting techniques showed that it was comfortable to apply the paint on a hardened but still moist surface and prewetting was not necessary (see Table 5 experiment nr 8).

Slight differences in the painting techniques appear when summarizing the microscopic evaluation of the paint layers. Based on the characteristic features, paintings can be roughly divided into four groups with the exception of Valjala figurative paintings. Based on samples collected from Koeru (15$^{th}$ century red), Türi, Martna (1st layer) and Valjala (architectural – see Figs. 12–14) it is evident that pigment was mixed with lime (visible lime inclusions and results of SEM-EDS). In addition we know that in Koeru 15th-century paintings lime-casein was used. Not all the studied samples were analysed for the content of organic binding media, but the use of lime-casein could apply in addition to Koeru paintings to other sites as well. Ground was previously limewashed and the calcium-rich layer is present between the paint and limewash/plaster layer(s). The thickness of paint layers is about 43,24–149,48 micrometres. Design of these paintings is sketched by using incisions on the fresh or semi-dry ground plaster.

Paint layers evaluated on the samples originating from Ambla, Järva-Peetri, Martna (2nd layer), Ridala (see Figs. 15–17) and Muhu churches were applied on the limewash as a very thin layer (starting

from about 4,99 μm up to 46,20 μm). In the case of Ridala the layer is almost transparent and well penetrated, about 19,69–97,69 μm into the limewash. Thin layers were most probably achieved by using just casein, lime-casein or lime water as binders to the pigment. Experiments (see Fig. 11) show that addition of casein to the limewash changes the properties of the paint – making it more liquid, which is helpful on the application of thin layers. However, it is also possible to achieve similar results with the paint based on water or lime water. Amongst very thin paint layers protein content was detected in the samples from Ambla (black paint), Järva-Peetri and Ridala (see Table 2), which possibly indicates the use of lime-casein or only casein as binder. Black paint collected from Ambla contained both lime and a series of amino acids referring to casein (see Table 2). The use of lime-casein paint seems to be applicable to paintings located in all the regions included in this study but needs ongoing research to prove that. Incisions were detected in Martna (on ground plaster) and Ridala (only selectively drawn on limewash).

Third group of samples are from Koeru (13th century) and Pöide (see Figs. 18–20). Both of the samples show two layers of limewash on top of the ground plaster.[32] Paint layer seems to be applied right after the application of the last limewash layer – no calcium-rich interface was detected between these layers. Interface is strongly present between the first and second limewash. Pigment was mixed with weakly dolomitic (Koeru) or dolomitic (Pöide) lime and the content of protein was detected (see Table 2), which again could indicate the use of lime-casein paint. Thickness of the paint layers is from about 39,68–108,48 μm. In Pöide incisions are sketched in ground plaster and in Koeru (13th century paintings) incisions can be found depending on the location on both preparatory layers – on the limewash and the ground plaster.

The last group consists of former exterior decorations from Kaarma (see Figs. 21–23) and Lüganuse. In both cases paint is applied directly to the ground plaster. Paintings from Kaarma are depicting frieze ornaments, which are painted with the combination of red, black (bluish shade) and white paint. After incisions were marked into fresh (but cured enough to be a solid support) and a rather smooth surface of plaster, it was continued with painting. Indication of this

32 Two layers of limewash were also recorded on the observed sample from Martna (2nd layer).



is that charcoal black pigment is well bound into the calcium-rich layer on top of the surface. Red pigment has penetrated deeper into the surface than black and a strong calcium-rich interface has formed under the paint layer, which could indicate that the ground was still fresh but a bit more dry than during the application of black paint. The application of black paint as the first step is also visible on the painting – in the centre of the ornament red is applied directly on the black areas (see Fig. 5). Pigments are probably mixed with just water or lime-water. If lime-casein paint was used on exteriors is not known so far. Façade paintings in Lüganuse are located on the Eastern and Western sides. On the Eastern side, only black pigment is used and on the Western side only red is used to highlight inscriptions and a cross. Both sides seem to be executed by the same master mason – the surface of ground plaster is with similar toolmarks (referring to the same hand) and incisions are marked into the fresh plaster. The rough look of the ground plaster makes an impression of a quick execution. On both sides pigment has penetrated into the surface and the calcium-rich interface is not visible under or on top of the paint.

Valjala figurative paintings are, compared to the other murals included in this study, exceptional mainly due to the noticeably better skills of the painter, differences in painting technique and the use of materials. On the site investigation works held in 2005 were a successful approach to clarify the technical aspects of these murals. Researchers concluded that paintings are executed on a dry ground plaster using *secco* painting technique. *Fresco* was excluded due to the absence of incisions and the fact that the painting continues without interruption over a plaster joint.[33] The painting is in the state of preservation where only underdrawings are visible and very small fragments of a more detailed pictorial layer remain. The fact that most of the finishing layer has been flaking and falling off the surface is another indicator to a *secco* technique. When layers are applied on wet or moist surfaces they are better adhered and longer lasting in time. During current study a sample from the remaining pictorial layer was observed and analysed. Results show that lead red pigment, which colour has altered during the time, is used. Calcium-rich interface was not detected between the limewash and paint

33 Werner Schmid, "Report on the results of the stratigraphic and painting technique studies of the St Martin's Church in Valjala", unpublished (2005), 20–22.

layer. Pigment particles are penetrated through the thin limewash layers until the calcium-rich layer between the ground plaster and limewash. Well penetrated pigment in the limewash can refer to a fresco on a limewash ground. The type of binding media for the pigment is currently not known.

Overall conclusions which can be drawn from the results gained through observations on the sites, analytical methods and microscopy are as follows:

Medieval master masons and painters used incisions to sketch the design of architectural paintings or inscriptions on the fresh plaster or limewash layer. This was done with the pointed object by freehand or using the help of a compass or a straight board. On figurative murals, incisions were noticed only in Ridala. It is quite clear that by that time the painter was on the site and paintings were done quite soon after the walls were plastered and limewashed.

Medieval Estonian murals are lime paintings with some variations in technique. The most common technique in the studied group of wall paintings is most likely lime *fresco* or lime *secco*, i.e. the paints used contained an admixture of lime, they can be characterized as a suspension composed of pigment, lime and water, possibly with the addition of milk proteins. Only in the case of exterior paintings can the use of a pure or lime *fresco* technique be assumed.

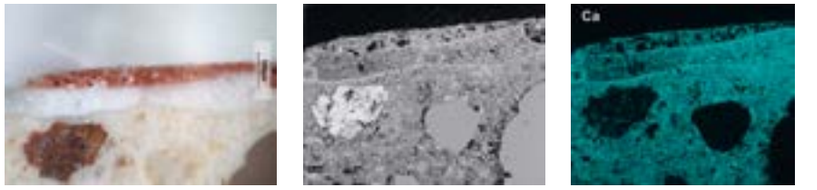
Distinction between these two techniques using SEM-EDS combined with optical microscopy is possible to a certain extent. While the criteria for *frescoes* executed before the initial carbonation process of the lime based ground materials is quite clear, distinction of lime *frescoes* and *secco* paintings is more complicated and dependent on the time of initial setting of the ground surface.

Magnesium compounds do not contribute to the formation of calcium rich interfaces. According to the results of elemental analysis including element mapping of polished cross sections there are no magnesium compounds in the 'lime skin' formed on the surfaces.

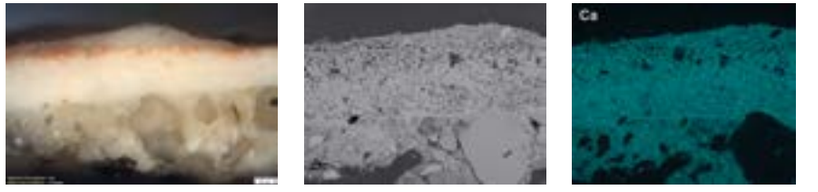
The presence of protein content in the paint layers was detected with clear positive result in the samples originating from Koeru (both 13$^{th}$ and 15$^{th}$ century paintings) and Järva-Peetri.

Results of GC-MS performed on paint layers from Ambla (13$^{th}$ century?) and Koeru (15$^{th}$ century) show the presence of a series of amino acids, most probably casein. So, we can assume that milk proteins were used as part of the binder in the paint layers.



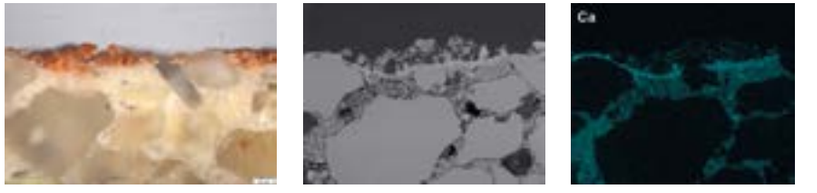



FIGS. 12–14. OPTICAL MICROSCOPE AND SEM-EDS ANALYSIS OF VALJALA ARCHITECTURAL PAINTINGS. FROM THE LEFT: POLARIZING LIGHT MICROSCOPE IMAGE (PLM), BACKSCATTERED ELECTRON (BSE) IMAGE AND CALCIUM DISTRIBUTION ON ELEMENTAL MAPPING.




FIGS. 15–17. OPTICAL MICROSCOPE AND SEM-EDS ANALYSIS OF RIDALA FIGURATIVE PAINTINGS. FROM THE LEFT: PLM IMAGE, BSE IMAGE AND CALCIUM DISTRIBUTION ON ELEMENTAL MAPPING.


FIGS. 18–20. OPTICAL MICROSCOPE AND SEM-EDS ANALYSIS OF PÖIDE ARCHITECTURAL PAINTINGS. FROM THE LEFT: PLM IMAGE, BSE IMAGE AND CALCIUM DISTRIBUTION ON ELEMENTAL MAPPING.




FIGS. 21–23. OPTICAL MICROSCOPE AND SEM-EDS ANALYSIS OF KAARMA EXTERIOR PAINTINGS. FROM THE LEFT: PLM IMAGE, BSE IMAGE AND CALCIUM DISTRIBUTION ON ELEMENTAL MAPPING.

Charcoal black and red ochres were used in almost all the examined paint samples. As an exception lead red was used to paint the Valjala figurative paintings.

Local calcitic, dolomitic or weakly dolomitic limes were used to prepare the mortars and limewashes.

**Varje Õunapuu, Hilkka Hiiop, Anneli Randla, Karol Bayer:** Evaluation of the Estonian Medieval Murals with the Focus on Painting Technique: Novel Findings on Paint Layer Composition

**Keywords:** medieval; murals; Estonia; technique; microscopy; lime; casein

## SUMMARY

The current study gives an analytical overview of the medieval (13th–15th century) wall-painting techniques and materials used in Estonia. The research is mainly based on visual observations at specific locations and on micro stratigraphic sample analysis using optical and electron microscopy and energy dispersive spectroscopy (EDS). Additionally, microchemical spot tests were carried out to determine the presence of organic additives in paint layers. Samples from twelve churches were examined (Ambla, Järva-Peetri, Koeru, Türi, Martna, Ridala, Muhu, Valjala, Pöide, Kaarma, Lüganuse, Haljala). Three paint layer samples, originating from Pöide, Koeru and Ambla churches, were analysed by the gas chromatography-mass spectrometry (GC-MS) method to determine the type of organic binder additives used in the paints. The article presents the information gained from the first analytical and comparative material study of the wall-paintings preserved in medieval Estonian church architecture. Microscopic analysis of the stratigraphy of plaster and paintings revealed the usual layered structure in the examined paintings: typically, a preparatory limewash layer was applied to the plaster before the mural painting, though in two cases, the painting was executed directly on the plaster. The findings indicate that dolomitic lime of different quality is the main and most common binder in both the underlying plasters and lime wash. Aerial calcitic lime was used for the limewash in only two paintings. Building on these insights, an experimental study was conducted to replicate the original technique, aiming to practically test the wall painting methods employed during the studied period. The focus is on the interior paintings as well as two examples of the exterior decoration. The study contributes to local and regional technical art history and to conservation specialists' better preservation decisions.



## CVs

**Varje Õunapuu** is a doctoral candidate and visiting lecturer at the Department of Cultural Heritage and Conservation, Estonian Academy of Arts. Her current research topic is medieval wall painting technologies. Since 2016 she has been a practicing wall-painting conservator in Estonia. During her studies and career she gained experience as an intern in Belgium and Italy and underwent professional training in several international workshops.

**Hilkka Hiiop** (PhD) is Professor at the Estonian Academy of Arts, Department of Cultural Heritage and Conservation and Dean of the Faculty of Art and Culture. Her PhD thesis dealt with the conservation management of contemporary art. She has studied and worked as a conservator in Berlin, Amsterdam and Rome, supervised a number of conservation and technical investigation projects in Estonia, curated exhibitions, and conducted scientific research on conservation and technical art history.

**Anneli Randla** (PhD) is the Head of the Department of Cultural Heritage and Conservation at the Estonian Academy of Arts, Senior Research Fellow and Associate Professor. Her research interests span medieval art and architecture, technical art history and conservation history.

**Karol Bayer** is a conservation scientist working at the Faculty of Restoration, University of Pardubice. He is currently Head of the Department of Chemical Technology and the Vice Dean for Science

and Research. Between 1984 and 1995 he was employed at the Institute for the Care of Monuments as part of the Slovak Republic State Studios for Restoration, Department of Technology, Bratislava, Slovak Republic. Since 1993 he has worked as an external lecturer at the University of Applied Arts in Vienna at the Institute of Restoration and Conservation. His main teaching and research activities are focused on material characteristics, the decay and conservation of stone, architectural surfaces and wall paintings. Within the frame of his research he concentrates mainly on the analysis and characterisation of historical mortars, conservation materials, and technologies for the conservation of stone and architectural surfaces. He has been involved in several international research projects, for example NANOLITH, the application of nanomaterials for sustainable conservation of historical works of sculpture and architecture constructed of Leitha limestone; NANOFORART, nano-materials for the conservation and preservation of movable and immovable artworks; STONECORE, stone conservation for the refurbishment of buildings, ROCARE, Roman cements for architectural restoration to new high standards; ROCEM, Roman cement to restore built heritage effectively; and NAMO, Nabatean mortars: technology and application. In the last years he has also been active in projects and cooperation focused on lifelong learning, mainly in the frame of international projects such as International Cooperation for Professional Training in Heritage Conservation: Heritage Train I and Heritage Train II.