Supplementary Materials

A multi- analytical approach for the characterization of seventeenth century decorative wall paintings in two Norwegian stave churches: a case study at Eidsborg and Heddal, Norway

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Pigments within the Norwegian artists' palette

Table S 1: List of pigments found in distemper wall paintings in Norwegian stave churches. Table S1 is adapted from Table 3 in Olstad [1] which complies the findings from two studies using IR spectroscopy, SEM, microscopic examination, and/or microchemical analysis [2, 3].

Colour	Pigment	Time period
White	Chalk	1600s-1700s
Yellow	Orpiment	1600s-1700s
	Yellow ochre / iron oxide	1600s-1700s
Red	Cinnabar	1600s-1700s
	Red lead	Medieval
	Red ochre/ iron oxide	1600s-1700s
Blue	Indigo	1600s-1700s
	Smalt	1600s-1700s
Black	Charcoal Black	1600s-1700s
	Bone char	Medieval &1600s-1700s

Table S 2: Colour and pigment assumption for the decor in Heddal and Eidsborg, as cited in conservation reports [4-6].

Colour	Pigment assumption	
	Heddal [4, 5]	**Eidsborg** [6]
Beige		Raw umbra and chalk
Black	Carbon based	Charcoal black
Green		Green earth and chalk
Pale green		Indigo and orpiment
Grey-brown		Raw umbra
Light grey	Chalk and carbon black	Chalk and charcoal black
Orange		Orpiment and English red
Pale pink / pink	Organic dye (possibly kermes or madder lake)	English red and chalk
Reddish yellow		Orpiment and English red
Brownish red		English red
Warm red		Cinnabar
		Orpiment and English red

Red	English red or red ochre	
White	Chalk	Chalk
White- greyish white		Chalk, possibly with charcoal black
Yellow		Orpiment

Structural and interior changes of Heddal and Eidsborg

Table S 3: Brief history of structural and interior changes of Heddal and Eidsborg, described in the conservation reports of Wedvik [4, 5] and Solberg, Norsted, and Spaarschuh [6].

	Heddal [4, 5]	**Eidsborg [6]**
1200-1300	Constructed in 1200s	Constructed 1250-1300
1600s	In the late 1600s, fixtures were mounted to the walls, galleries were added to the nave, and the medieval décor was overpainted with a glue-based paint.	The northern wall of the nave was rendered in 1604, whereas the southern wall is dated as 1640/49.
1800s	Between 1849 and 1851, the Baroque restorations were removed, and the decorative wall paintings were covered with panels. Concurrently, the structure underwent its first reconstruction.	Eidsborg was rebuilt twice, once in 1826 and later in 1845. During these reconstructions, the nave was extended, widows were inserted into the nave's southern wall, and the interior décor was covered with panels.
1900s	The third and final restoration of the interior was performed between 1930 and 1955, in which the 19th century panelling was removed revealing the 17th century distemper paint and fragmented medieval décor. Once the pictorial layer was exposed, consolidation and extensive retouching were performed. Additionally, in the 1950s, the wooden structure was "restored" to its medieval configuration.	In the 1920s, in an attempt to return the church to its medieval appearance, most of the 19th century alterations were removed. The wall panelling was taken down and the large 19th century windows were replaced with smaller ones. During this reconstruction, the décor on the nave's southern wall suffered and consequently preservation measures were taken.
2000s	Prior to the 2009 consolidation treatment, dust and debris removal was carried out with a brush, whereas spot cleaning was performed with a damp compress. In addition, thick adhesive layers from the 1950s treatment, were softened with water and mechanically removed from the wall.	Due to the overall fragility of the décor within Eidsborg (i.e., water sensitivity and loss in cohesive and adhesive properties), neither aqueous cleaning nor dusting was conducted prior to the 2007 consolidation treatment. Although after the consolidant dried, localized debris removal was achievable from the décor's surface.
	For both churches, localized consolidation was achieved by applying sturgeon glue to the flaking paint through Japanese tissue paper. Specifically, for Eidsborg it was found that a 2.5 % solution of sturgeon glue was most ideal, whereas in Heddal a 2 % solution was used. Following this treatment, and before drying, excess glue was removed from the Japanese paper by blotting.	
	In 2013 an assessment of these consolidation treatments was performed, and further adhesive or cohesive failure was observed [7]. Consequently, in 2014 NIKU and Riksantikvaren developed a joint project to better understand the overall effects of sturgeon glue. The Sturgeon Glue Project is still ongoing.	

Sample collection

On 27th of September 2018, a sampling campaign was carried out at Heddal and Eidsborg stave church, within the framework of Sustainable Management of heritage Buildings in a Long-term perspective (SyMBoL) Project (Project No. 274749). The sampling concentrated on areas of red pigments within the distemper decorative wall paintings.

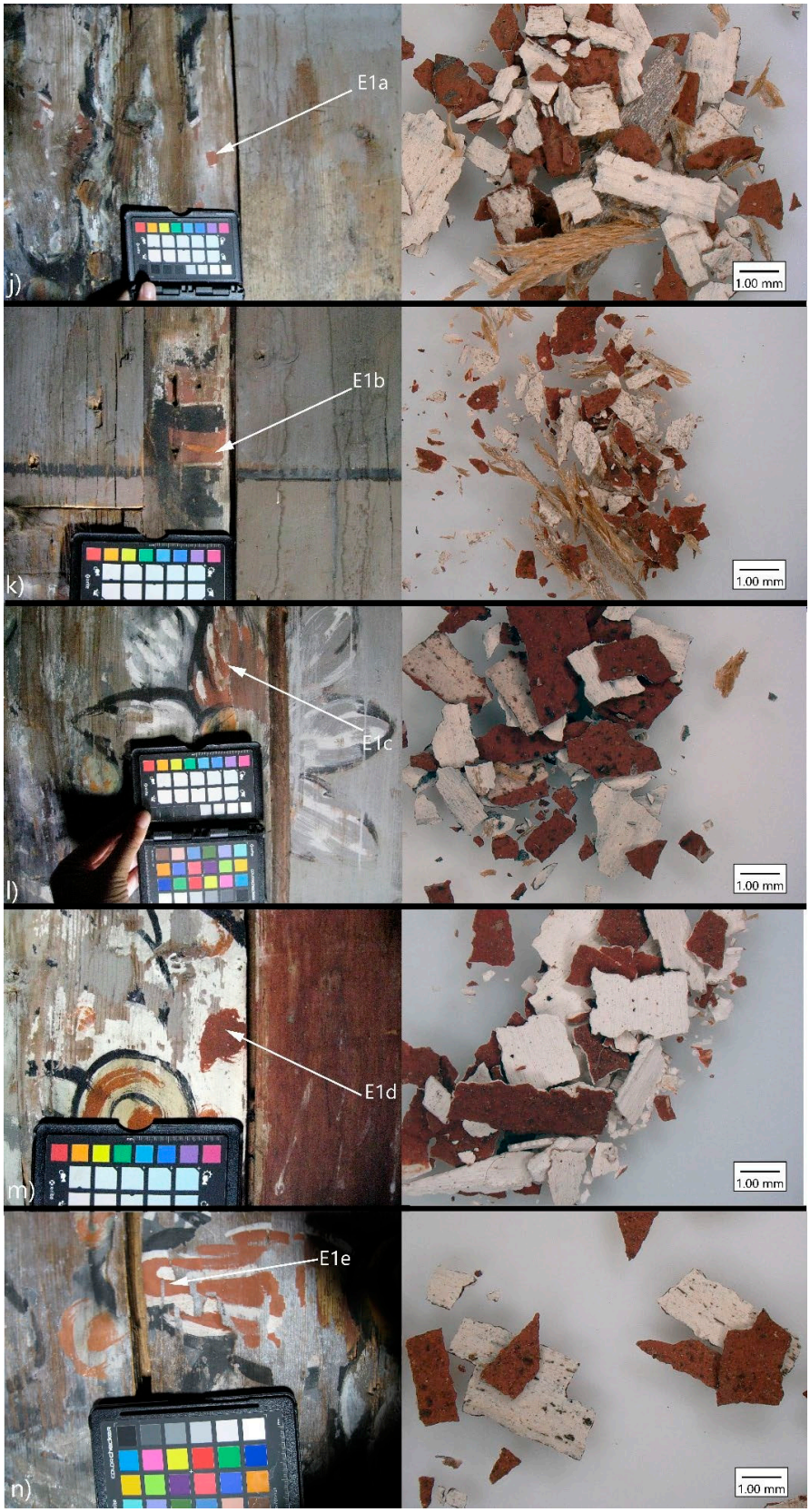
Table S 4: Sample description and sampling location in nave of Heddal and Eidsborg. Sample naming convention: name of church, sample category (1 – treated with sturgeon glue, 2- untreated, 3- treated with sturgeon glue and in poor condition), letter signifying specific sample. See **Figure S 1** for visual representation of sampling location and specimen collected. See manuscript for map of sampling points (**Figure 3**).

sample description and sampling location			
H1a: four-layered stratigraphy (red, grey, orange, white)			
Northern wall	2nd plank from the north-west post	180 cm from the floor	25 cm from the north-west post
H1b: four-layered stratigraphy (red, grey, orange, white)			
Northern wall	3rd plank from the north-west post	166 cm from the floor	66 cm from the north-west post
H1c: four-layered stratigraphy (red, grey, orange, white)			
Northern wall	3rd plank from the north-west post	193 cm from the floor	84 cm from the north-west post
H1d: three-layered stratigraphy (red, grey, white)			
Northern wall	2nd plank from the door's proper right	228 cm from the floor	75 cm to the right from the door in the middle of the wall
H1e: four-layered stratigraphy (red, grey, black, white)			
Northern wall	2nd plank from the door's proper right	233 cm from the floor	58 cm from the door to the right.
H2a: three-layered stratigraphy (red, grey, white)			
Northern wall	1st plank from the north-east post	310 cm from the floor	22 cm from the post to the right.
H2b: four-layered stratigraphy (red, grey, black, white)			
Northern wall	4th plank from the north-east post	332 cm from the floor	96 cm from the post to the right.
H2c: four-layered stratigraphy (red and white, grey, red, white)			
Northern wall	3rd plank from the north-east post	341 cm from the floor	57 cm from the post to the right.
H2d: four-layered stratigraphy (red, grey, orange, white)			
Northern wall	6th plank from the north door	285 cm from the floor	232 cm from the north portal.
H2e: four-layered stratigraphy (red, grey, orange, white)			
Northern wall	6th plank from the north eastern corner post	260 cm from the floor	202 cm from the north portal

H3a: five-layered stratigraphy (red and white, grey, black, orange, white)			
Northern wall	3rd plank from the post to the left.	150 cm from the floor	65 cm from the post to the left
E1a: three-layered stratigraphy (red, black, white)			
Southern wall	8th plank from main entrance	158 cm from the floor	10 cm from the windowsill
E1b: two-layered stratigraphy (red on white)			
Southern wall	8th plank from main entrance	192 cm from the floor	8 cm from the windowsill
E1c: three-layered stratigraphy (red, black, white)			
Southern wall	4th plank from the post to the left	164 cm from the floor	141 cm from the post to the left
E1d: two-layered stratigraphy (red on white)			
Southern wall	2nd plank from the post to the left	181 cm from the floor	65 cm from the windowsill
E1e: three-layered stratigraphy (red, black, white)			
Southern wall	3rd plank from main entrance	153 cm from the floor	190 cm from the post to the right
E2a: three-layered stratigraphy (red, black, white)			
Northern wall	4th plank from the north-west post	220 cm from the floor	145 cm from the north-west post
E2b: three-layered stratigraphy (red, black, white)			
Northern wall	5th plank from the north-west post	183 cm from the floor	181 cm from the north-west post
E2c: three-layered stratigraphy (red, black, white)			
Northern wall	5th plank from the north-west post	183 cm from the floor	179.5 cm from the north-west post
E2d: three-layered stratigraphy (red, black, white)			
Northern wall	7th plank from the north-east post	188 cm from the floor	235 cm from the north-east post
E3a: two-layered stratigraphy (red on white)			
Southern wall	1st plank from the south-west post	270 cm from the floor	27 cm from the south-west post


H1a
a)
1.00 mm
H1b
b)
1.00 mm
H1c
c)
1.00 mm
H1d
d)
1.00 mm
H1e
e)
1.00 mm


H2a
f)
1.00 mm
H2b
g)
1.00 mm
H2c
h)
1.00 mm
H3a
i)
1.00 mm


E1a
j)
1.00 mm
E1b
k)
1.00 mm
E1c
l)
1.00 mm
E1d
m)
1.00 mm
E1e
n)
1.00 mm


E2a
o)
1.00 mm
E2b
p)
1.00 mm
E2c
q)
1.00 mm
E2d
r)
1.00 mm
E3a
s)
1.00 mm

Figure S 1: Image of sample location within Eidsborg and Heddal and microscopic image of collected specimen. (Left image): Arrow identifying sample location prior to sampling, (Right image): microscope image of collected sample (100x). Refer to **Table S 4** for numerical location of sampling and description.

Chemical Composition of intermediate layers

All Heddal samples contained a grey pigmented layer, which similarly to the white ground layer, mainly consists of a Ca-based material (**Figure S 5**). In [5, 6], the light grey/whitish-grey layer found for both churches is assumed to be a mixture of chalk and carbon black. Although, it is not possible to identify carbon black by means of SEM-EDS. Two of these Heddal samples (H1a and H1b) also contained an orange layer (**Figure S 2**) which displayed similar EDS results compared to that of the red layer. These results suggest that, like the red pigmented layer, the orange layer is also an ochre pigment. Although the orange layer probably contains goethite (FeOOH) as dominant colouring phase, which is in agreement with previous findings of 1600s -1700s distemper paints from other stave churches [1].

Three of the examined cross-sectional samples contained a black layer (E1a, E1c, and H1e). The EDS results obtained for this layer showed the occurrence of Ca, Si, and Al, as the most common constituents. The most prevalent difference between the black layers within these two churches is the weight percentage of these elements. The results for Eidsborg are rich in Ca (>89 wt. %) and contain relevantly low amounts (1-3 wt. %) of Si and Al, whereas these three components are considered as a major component (>10 wt. %) for the Heddal specimen (H1e). Additionally, H1e contained minor amounts of P (3 wt. %). Although only one sample from Heddal contained a black layer (H1e), the combined presence of Ca and P in this sample is suggestive of a bone black pigment. However, the FT-IR spectrum acquired from H1e did not permit a definitive confirmation of calcium phosphate (presumably in form of hydroxyapatite) as hypothesized from EDS data: its main band could contribute to the shoulder observed at ~1114 cm^{-1}, even if the total amount of such phase is (if present) probably too low to be actively responsible for any of the identified features. Although, previous examination of other Norwegian 1600s-1700s polychrome wall paintings has identified the black layer as charcoal black or bone char [1] (**Table S 1**), which is in agreement of the pigment assumptions of Heddal[4] and Eidsborg [6] (complied in **Table S 2**).

Microscopic analysis: optical microscopy and scanning electron microscopy

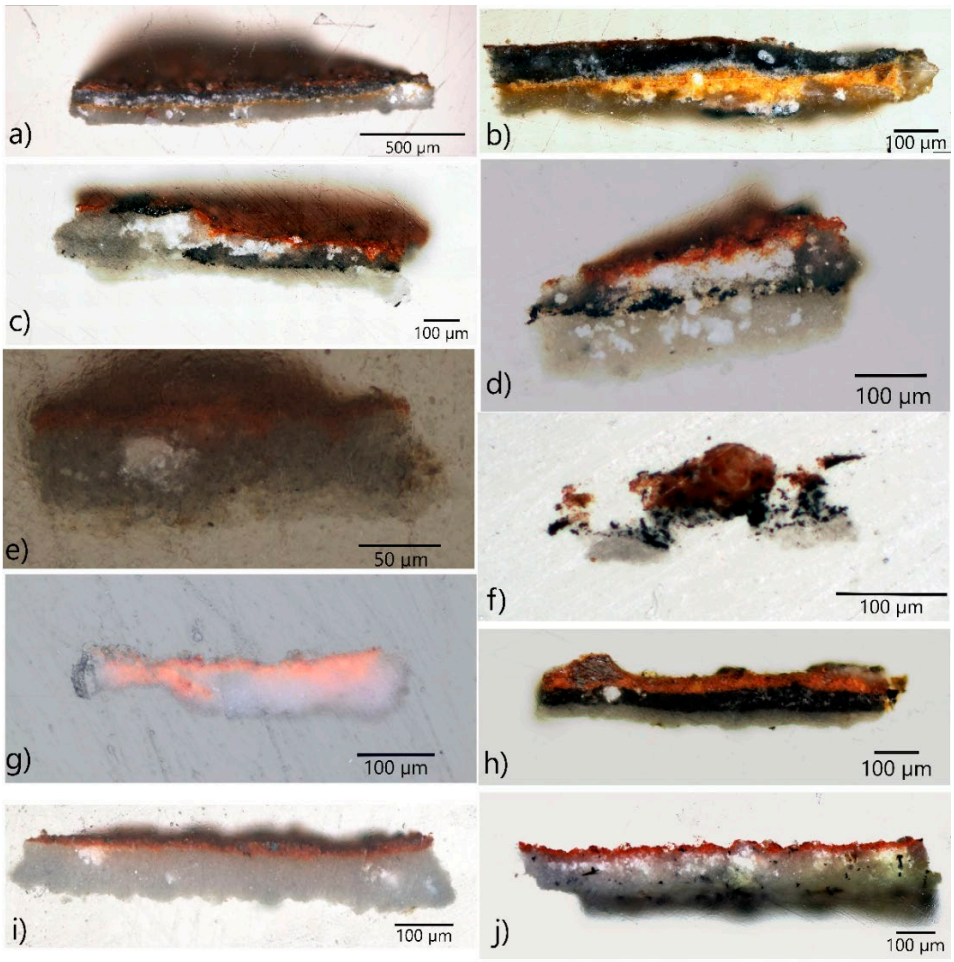


Figure S 2: Microscopy images of cross-sectional samples from Heddal and Eidsborg: a) H1a, b) H1b, c) H1d, d) H1e, e) H2a, f) E1a, g) E1b, h) E1c, i) E1d, and j) E2a. Cross-sectional samples were prepared by embedding distemper paint fragments in Technovit® 2000 LC (Heraeus Kulzer, Germany)

Table S 5: Summary of cross-sectional sample's stratigraphy through microscopy analysis, where ND means not detected. See **Figure S 1** for corresponding microscopic image of samples.

Thickness of layer (µm)	H1a	H1b	H1d	H1e	H2a	E1a	E1b	E1c	E1d	E2a
Red	27 - 33	10 - 14	15 - 20	17 - 28	7 - 13	ND	19-35	53 -78	18- 28	15 - 25
Grey	39 - 79	33 - 79	38 -144	43 - 74	34 - 49					
Orange	14 – 20	26 - 61								
Black				12 - 27		ND		40 -54		
White	93 - 127	49 - 65	37 - 61	82 - 85	13 - 24	ND	45-87	21 - 46	87 - 103	80 - 90

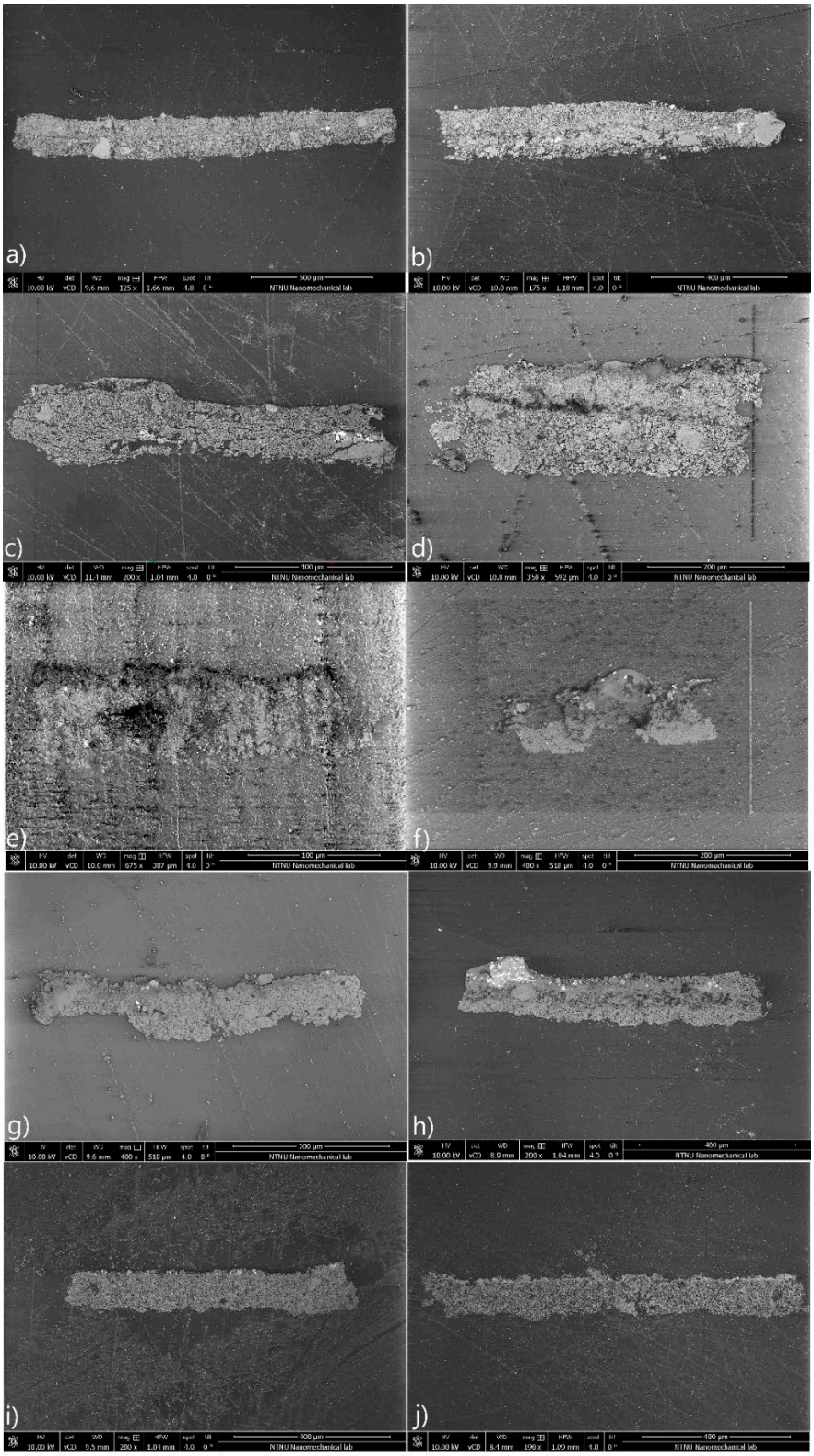


Figure S 3: SEM-BSE images of cross-sectional from Heddal and Eidsborg: a) H1a, b) H1b, c) H1d, d) H1e, e) H2a, f) E1a, g) E1b, h) E1c, i) E1d, and j) E2a. See **Figure S 2** for microscopic image of cross-sectional samples.

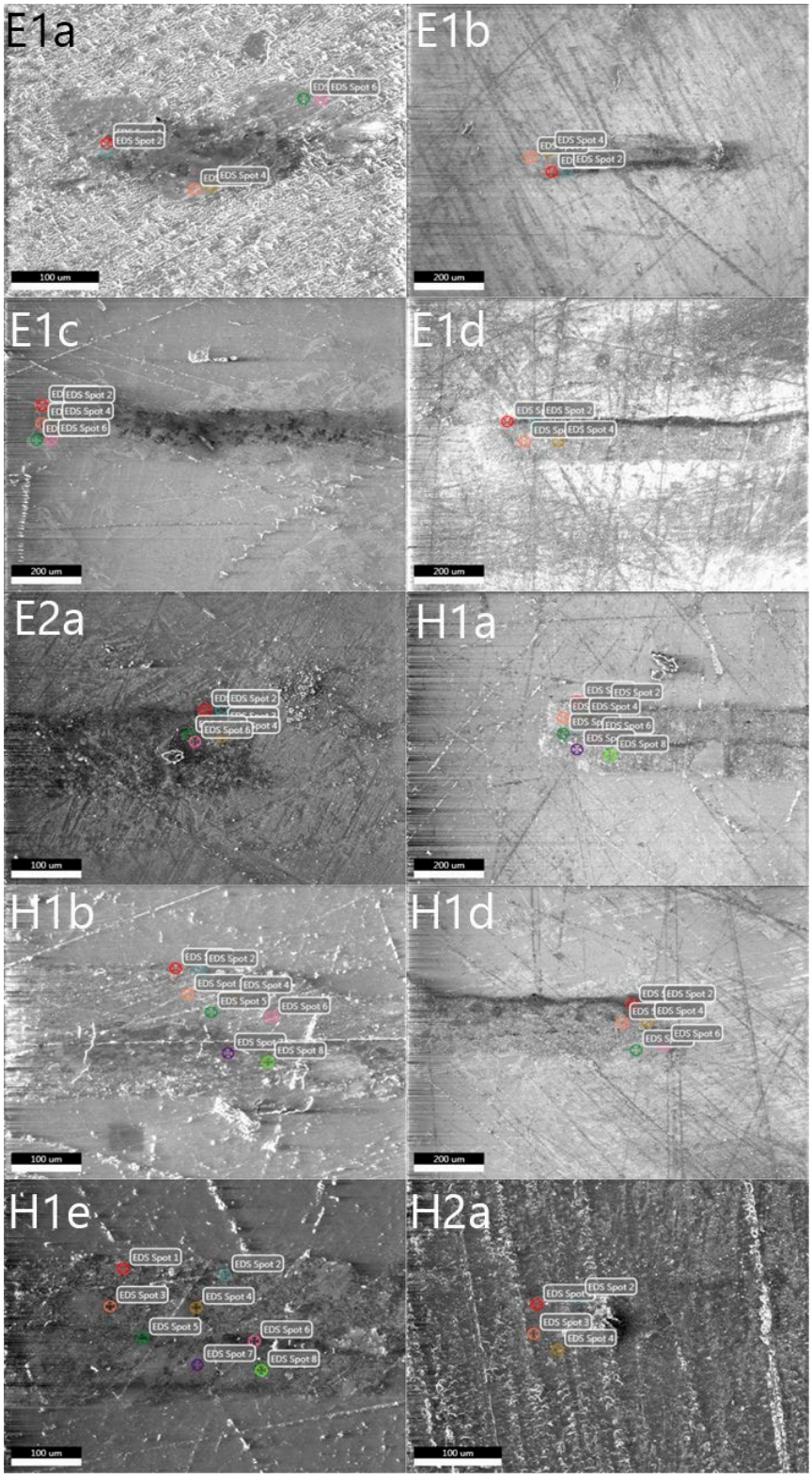
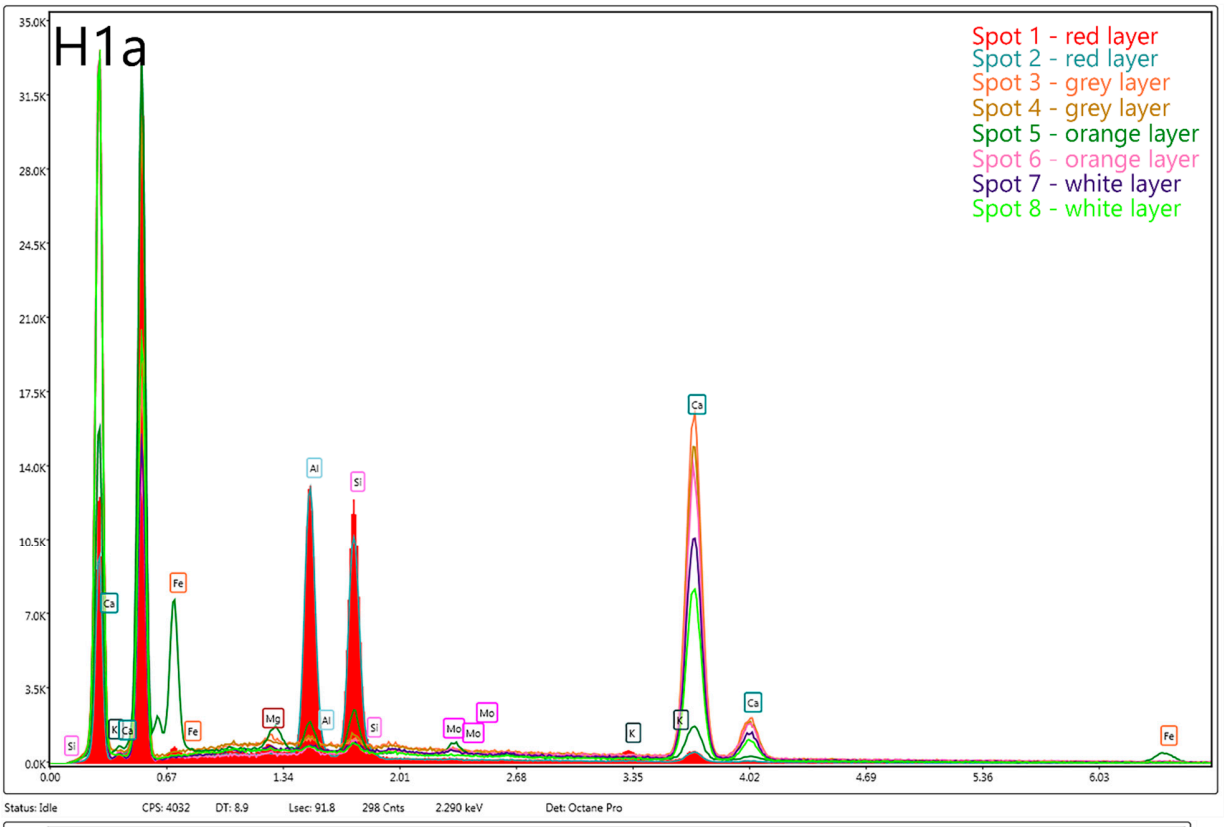
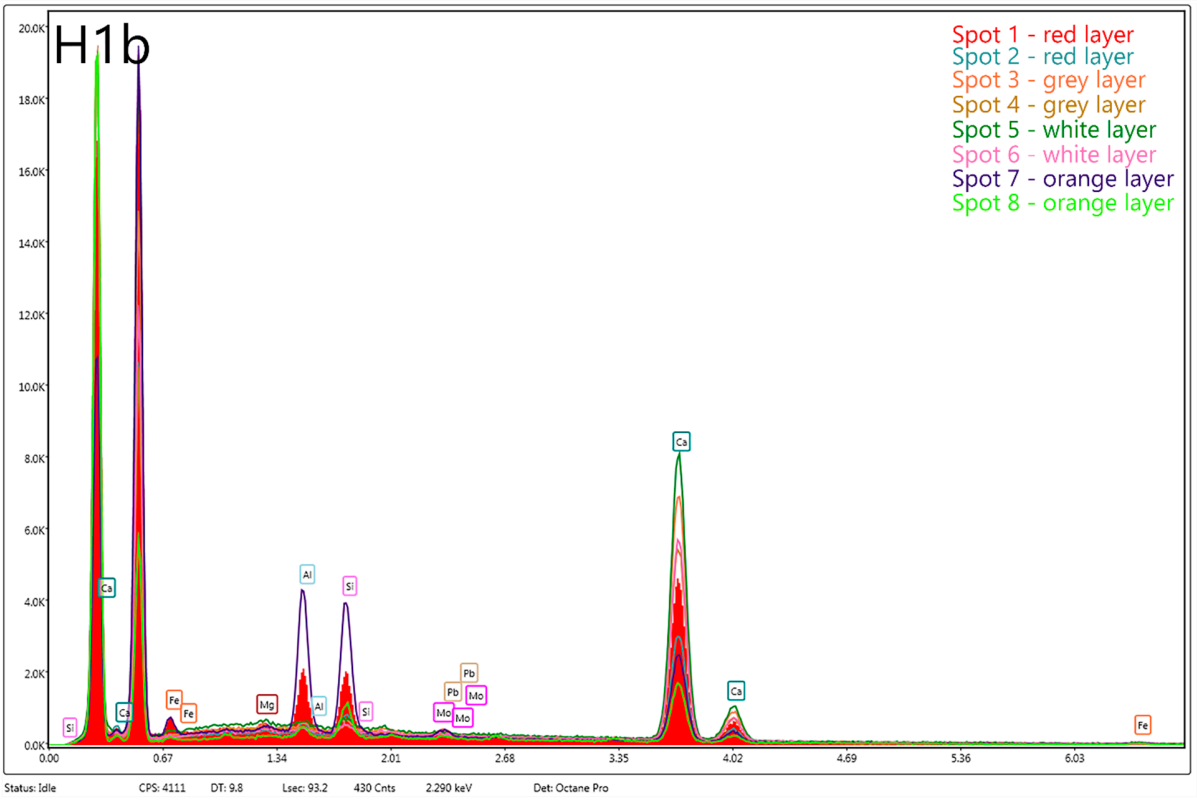
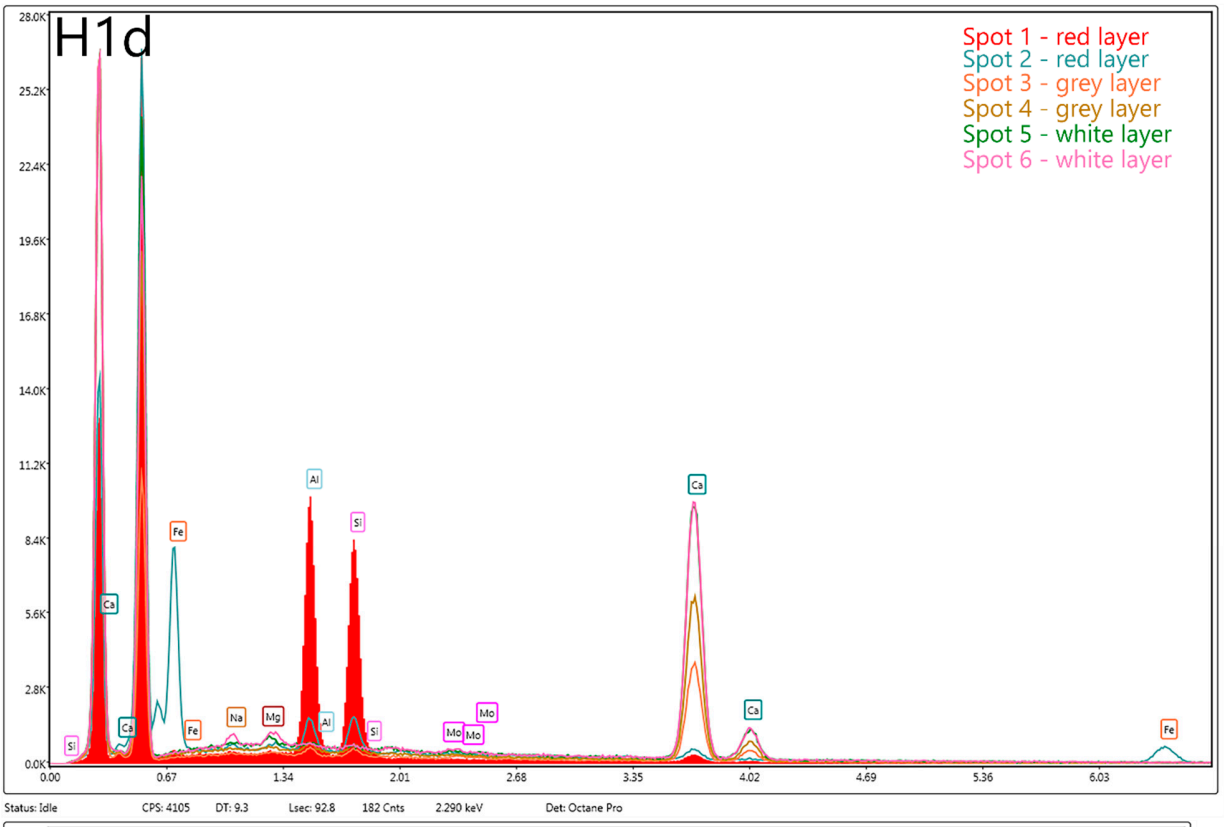
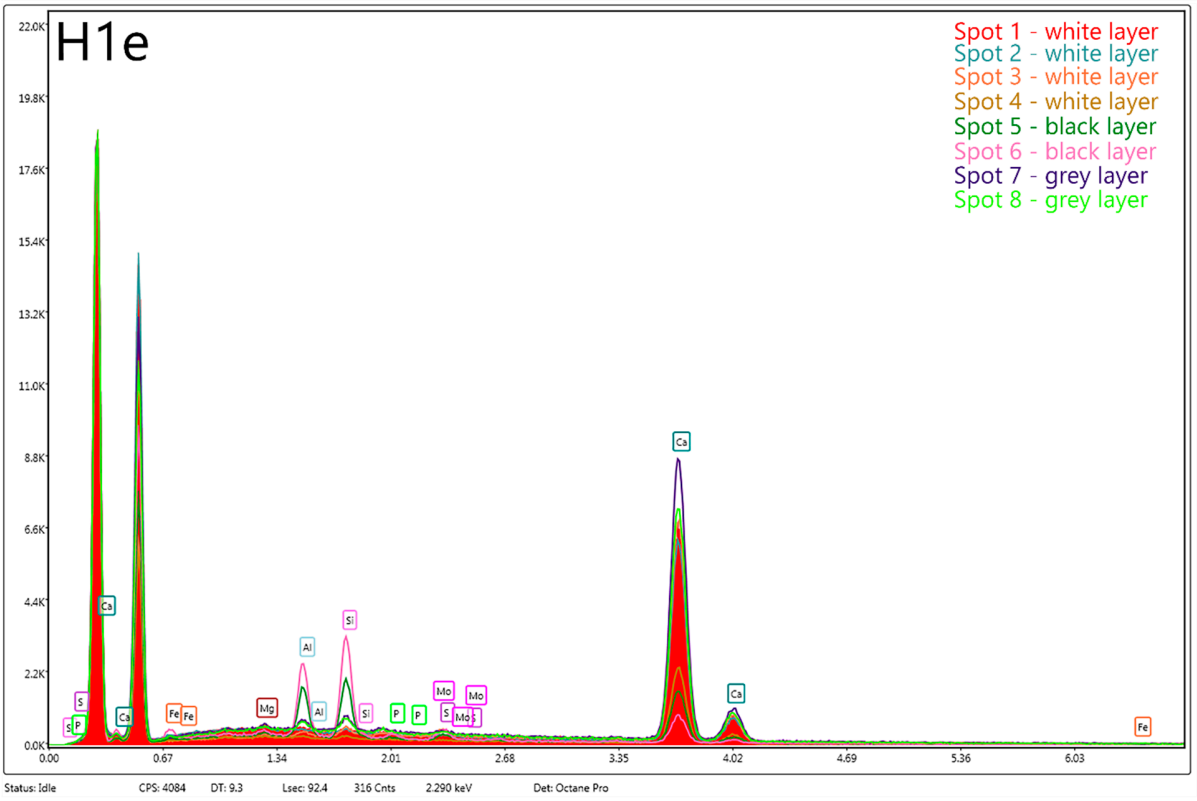


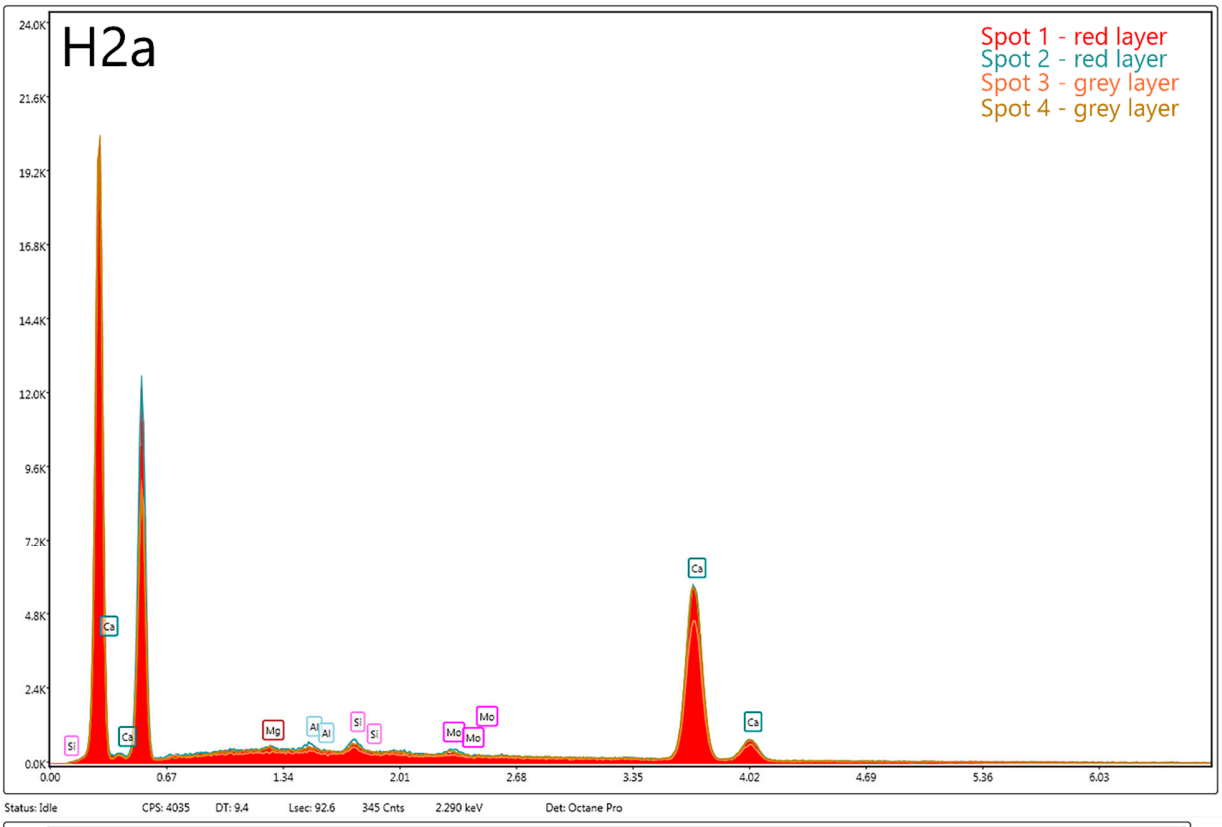
Figure S 4: Spot analysis images of cross-sectional samples

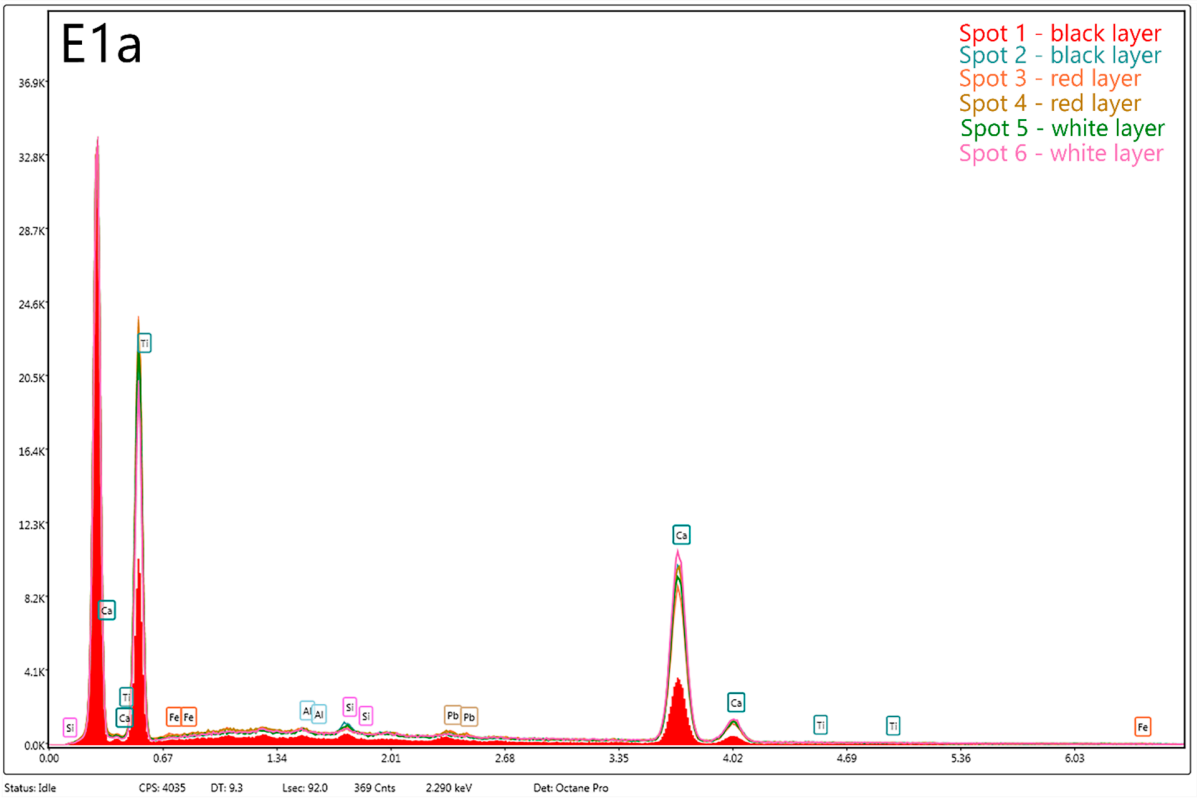

H1a
Spot 1 - red layer
Spot 2 - red layer
Spot 3 - grey layer
Spot 4 - grey layer
Spot 5 - orange layer
Spot 6 - orange layer
Spot 7 - white layer
Spot 8 - white layer
35.0K
31.5K
28.0K
24.5K
21.0K
17.5K
14.0K
10.5K
7.0K
3.5K
0.0K
0.00
0.67
1.34
2.01
2.68
3.35
4.02
4.69
5.36
6.03
Si
Ca
K
Fe
Mg
Al
Mo
Status: Idle
CPS: 4032
DT: 8.9
Lsec: 91.8
298 Cnts
2.290 keV
Det: Octane Pro

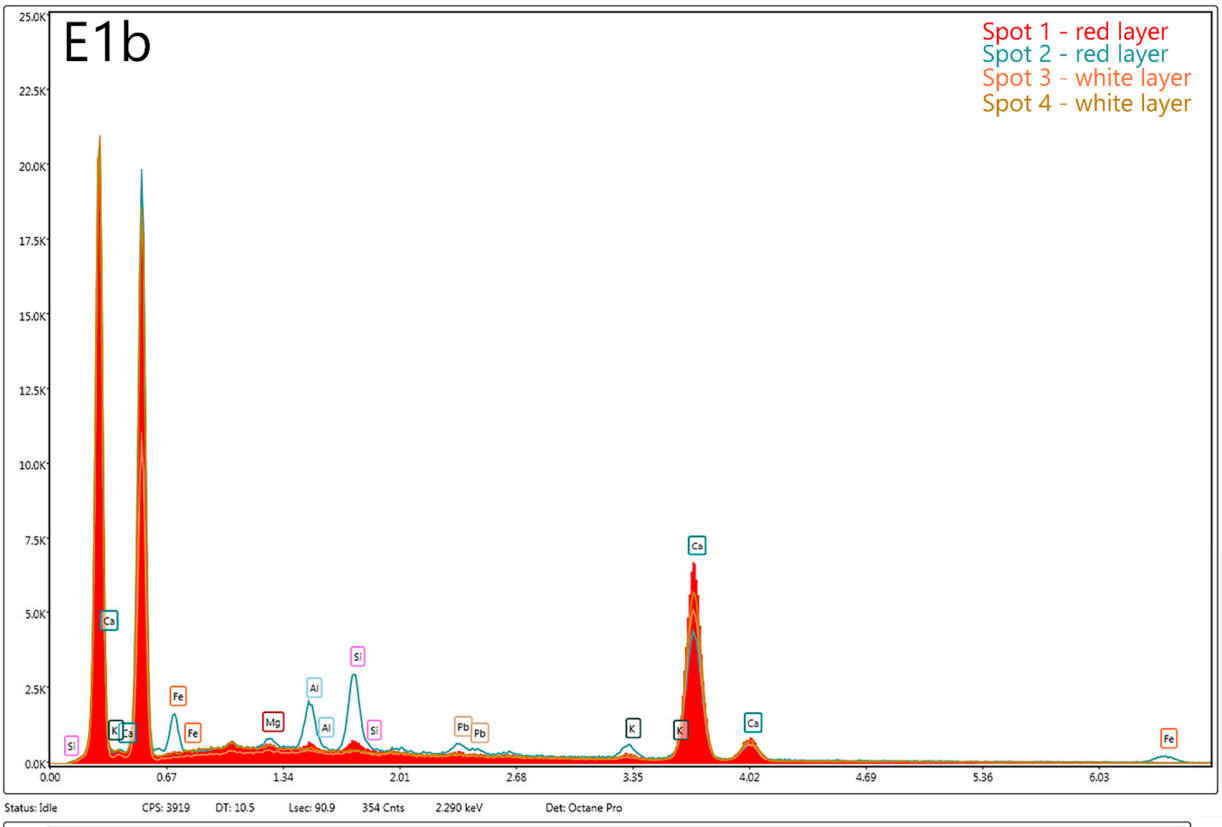

H1b
Spot 1 - red layer
Spot 2 - red layer
Spot 3 - grey layer
Spot 4 - grey layer
Spot 5 - white layer
Spot 6 - white layer
Spot 7 - orange layer
Spot 8 - orange layer
20.0K
18.0K
16.0K
14.0K
12.0K
10.0K
8.0K
6.0K
4.0K
2.0K
0.0K
0.00
0.67
1.34
2.01
2.68
3.35
4.02
4.69
5.36
6.03
Si
Ca
Fe
Mg
Al
Pb
Mo
Status: Idle
CPS: 4111
DT: 9.8
Lsec: 93.2
430 Cnts
2.290 keV
Det: Octane Pro

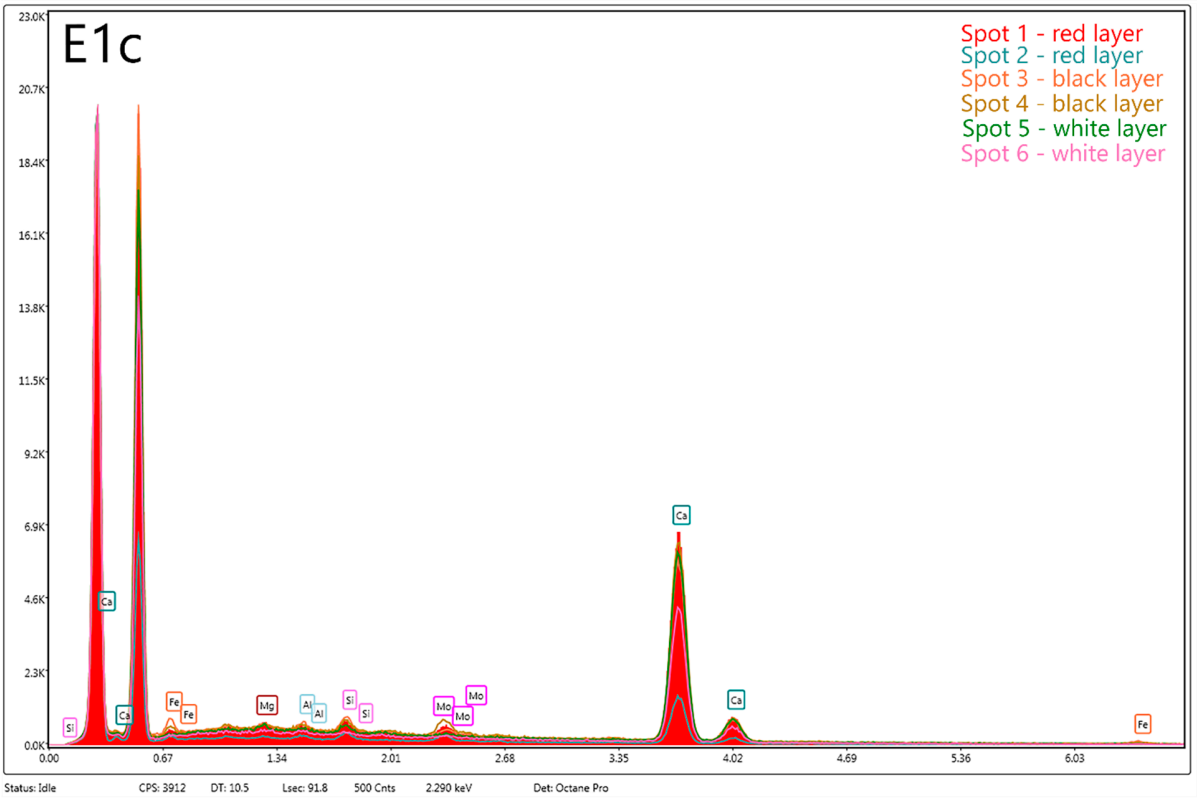

H1d
Spot 1 - red layer
Spot 2 - red layer
Spot 3 - grey layer
Spot 4 - grey layer
Spot 5 - white layer
Spot 6 - white layer
28.0K
25.2K
22.4K
19.6K
16.8K
14.0K
11.2K
8.4K
5.6K
2.8K
0.0K
0.00
0.67
1.34
2.01
2.68
3.35
4.02
4.69
5.36
6.03
Si
Ca
Fe
Na
Mg
Al
Mo
Status: Idle
CPS: 4105
DT: 9.3
Lsec: 92.8
182 Cnts
2.290 keV
Det: Octane Pro


H1e
Spot 1 - white layer
Spot 2 - white layer
Spot 3 - white layer
Spot 4 - white layer
Spot 5 - black layer
Spot 6 - black layer
Spot 7 - grey layer
Spot 8 - grey layer
22.0K
19.8K
17.6K
15.4K
13.2K
11.0K
8.8K
6.6K
4.4K
2.2K
0.0K
0.00
0.67
1.34
2.01
2.68
3.35
4.02
4.69
5.36
6.03
S
P
Ca
Fe
Mg
Al
Si
Mo
Status: Idle
CPS: 4084
DT: 9.3
Lsec: 92.4
316 Cnts
2.290 keV
Det: Octane Pro


H2a
Spot 1 - red layer
Spot 2 - red layer
Spot 3 - grey layer
Spot 4 - grey layer
24.0K
21.6K
19.2K
16.8K
14.4K
12.0K
9.6K
7.2K
4.8K
2.4K
0.0K
0.00
0.67
1.34
2.01
2.68
3.35
4.02
4.69
5.36
6.03
Si
Ca
Ca
Mg
Al
Al
Si
Si
Mo
Mo
Mo
Ca
Ca
Status: Idle
CPS: 4035
DT: 9.4
Lsec: 92.6
345 Cnts
2.290 keV
Det: Octane Pro


E1a
Spot 1 - black layer
Spot 2 - black layer
Spot 3 - red layer
Spot 4 - red layer
Spot 5 - white layer
Spot 6 - white layer
36.9K
32.8K
28.7K
24.6K
20.5K
16.4K
12.3K
8.2K
4.1K
0.0K
0.00
0.67
1.34
2.01
2.68
3.35
4.02
4.69
5.36
6.03
Si
Ti
Ca
Ti
Ca
Fe
Fe
Al
Al
Si
Si
Pb
Pb
Ca
Ca
Ti
Ti
Fe
Status: Idle
CPS: 4035
DT: 9.3
Lsec: 92.0
369 Cnts
2.290 keV
Det: Octane Pro


E1b
Spot 1 - red layer
Spot 2 - red layer
Spot 3 - white layer
Spot 4 - white layer
25.0K
22.5K
20.0K
17.5K
15.0K
12.5K
10.0K
7.5K
5.0K
2.5K
0.0K
0.00
0.67
1.34
2.01
2.68
3.35
4.02
4.69
5.36
6.03
Si
Ca
K
Ca
Fe
Fe
Mg
Al
Al
Si
Si
Pb
Pb
K
K
Ca
Ca
Fe
Status: Idle
CPS: 3919
DT: 10.5
Lsec: 90.9
354 Cnts
2.290 keV
Det: Octane Pro


E1c
Spot 1 - red layer
Spot 2 - red layer
Spot 3 - black layer
Spot 4 - black layer
Spot 5 - white layer
Spot 6 - white layer
23.0K
20.7K
18.4K
16.1K
13.8K
11.5K
9.2K
6.9K
4.6K
2.3K
0.0K
0.00
0.67
1.34
2.01
2.68
3.35
4.02
4.69
5.36
6.03
Si
Ca
Ca
Fe
Fe
Mg
Al
Al
Si
Si
Mo
Mo
Mo
Ca
Ca
Fe
Status: Idle
CPS: 3912
DT: 10.5
Lsec: 91.8
500 Cnts
2.290 keV
Det: Octane Pro

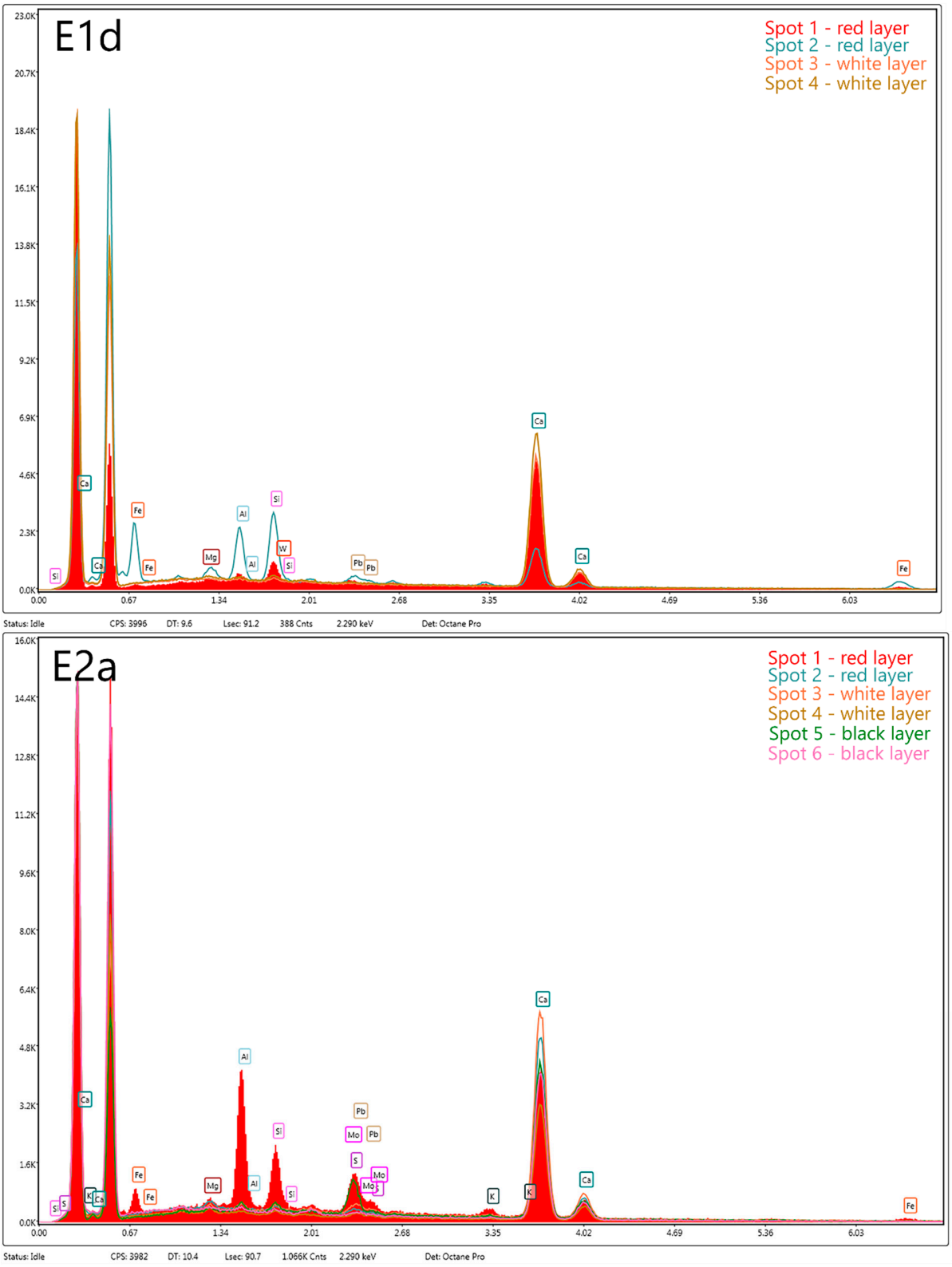


Figure S 5: EDS spectrum of historic paint samples from Heddal and Eidsborg

Table S 6: Summary of common ESEM-EDS results of samples from Eidsborg and Heddal. Concentrations higher than 10 weight per cent (wt. %) are considered major, whereas minor concentrations are between 1 - 10 wt.%. Values lower than 1 are not listed. See following tables for wt.% values.

Colour	SEM-EDS		Sample location
	Major constitutes	Minor constitutes	
Red	Fe, Ca, Al, Si	Mg, S, K	H1a, H1d
	Fe, Ca, Al	Si, Mg, S, K	E2a
	Fe, Ca	Al, Si, Mg, S, K	E1c, H1b, H2a[1]
	Fe, Ca	Al, Si, Mg, S, K, Pb	E1a[1], E1b
	Fe, Ca, Al, Si	Mg, S, K, Pb	E1d
Grey	Ca	Al, Si, Mg,	H1a, H1b, H1d, H1e, H2a
Orange	Fe, Ca, Al, Si	Fe, Ca, Pb, Mg,	H1b
	Fe, Ca,	Fe, Ca, Al, Si*, Pb, Mg,	H1a
Black	Ca, Al, Si	Fe, Pb, P, Mg,	H1e
	Ca	Al, Si, Fe, Pb, P, Mg,	E1a, E1c, E2a
White	Ca	Al, Si, Mg	H1a, H1b, H1e, H2a, E1a, E1b, E1c, E1d
	Ca	Al, Si, Mg, Na	H1d
	Ca	Al, Si, Mg, Pb	E2a

[1]Fe was not found using EDS spot analysis, but was confirmed with XRD

Concentrations higher than 10 wt.% can be considered major, whereas minor concentrations are between 1 - 10 wt.%, and concentrations lower than 1 are not listed.

Table S 7: EDS results of red layer

Red Layer											
sample name	spot	Al	Si	Ca	Fe	Pb	K	Mg	Mo	W	S
		Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %
E1a	3	1.81	1.72	91.48		4.58					
E1a	4			96.17		3.83					
E1b	1		1.23	98.19							
E1b	2	5.47	9.33	63.77	10.83	4.79	4.64	1.18			
E1c	1	1.44	1.90	90.55				1.49	3.90		
E1c	2	2.58	3.99	79.12	3.96			1.58	8.76		
E1d	1		2.51	95.29						1.46	
E1d	2	12.60	16.77	41.93	15.89	9.52		3.28			
E2a	1	13.77	5.85	67.45	1.15		2.90				8.23
E2a	2			97.08					1.56		
H1a	1	37.52	45.88	7.31	1.92		5.50	1.87			
H1a	2	43.69	47.86	8.45							
H1b	1	7.13	7.34	76.26	4.13			1.48	3.66		
H1b	2	3.28	4.82	85.82					6.07		
H1d	1	43.15	47.60	6.32	1.26			1.66			
H1d	2	7.96	8.44	10.05	73.55						
H2a	1	1.55	2.06	92.71				1.41	92.71		
H2a	2	1.61	2.11	92.07				1.01	3.19		

Table S 8: EDS results of black layer and black particles

Black Layer											
sample name	spot	Al	Si	Ca	Fe	Pb	P	Ti	Mg	Mo	S

		Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %
E1a	1	2.51	3.04	94.16							
E1a	2		1.36	96.46		1.84					
E1c	3	1.81	2.55	87.05	4.43				1.43	2.73	
E1c	4	1.36	1.94	89.53	1.58					5.59	
H1e	5	13.43	16.48	62.49					1.84	5.76	
H1e	6	20.00	29.97	33.00	4.46		3.45		2.96		6.17
					Black Particles						
E2a	5	2.11	2.08	79.13		6.22			1.41	9.05	
E2a	6	1.55	1.18	93.75					1.38	2.14	

Table S 9: EDS results of grey layer

		Grey Layer				
sample name	spot	Al	Si	Ca	Mg	Mo
		Weight %	Weight %	Weight %	Weight %	Weight %
H1a	3			99.04		
H1a	4			98.84		
H1b	3	1.21	1.60	97.19		
H1b	4			98.95		
H1d	3	1.02	1.32	97.66		
H1d	4			98.52		
H1e	7		0.98	98.59		
H1e	8	1.21	1.78	94.49		1.93
H2a	3		1.20	98.53		
H2a	4	1.07	1.68	93.95		2.48

Table S 10: EDS results of orange layer

		Orange Layer						
sample name	spot	Al	Si	Ca	Fe	Pb	Mg	Mo

		Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %
H1a	5	5.98	8.43	27.02	44.27		6.17	8.12
H1a	6		1.46	97.80				
H1b	7	19.33	19.06	52.80	2.52		1.65	4.63
H1b	8	2.76	10.96	81.97		4.30		

Table S 11: EDS results of white layer

				White Layer				
sample name	spot	Na	Al	Si	Ca	Pb	Mg	Mo
		Weight %	Weight %	Weight %	Weight %	Weight %	Weight %	Weight %
E1a	5			1.22	98.44			
E1a	6			1.18	97.94			
E1b	3			1.26	98.74			
E1b	4			1.03	98.97			
E1c	5				98.56			
E1c	6		1.62	1.51	96.87			
E1d	3		1.32	1.39	96.15		1.14	
E1d	4		1.17	1.50	96.14		1.19	
E2a	3		1.78	1.67	89.26	2.82	1.49	2.98
E2a	4		1.71	1.46	91.22	3.81	1.80	
H1a	7			1.10	98.31			
H1a	8		1.29	1.81	96.89			
H1b	5		1.40	1.66	95.65		1.29	
H1b	6			1.06	98.70			
H1d	5				98.98			
H1d	6	1.85	1.19	1.00	91.69		2.18	2.08
H1e	1				99.09			
H1e	2				99.12			
H1e	3		1.07	1.72	92.59			4.62
H1e	4				98.65			

Fourier-Transform Infrared Spectroscopy

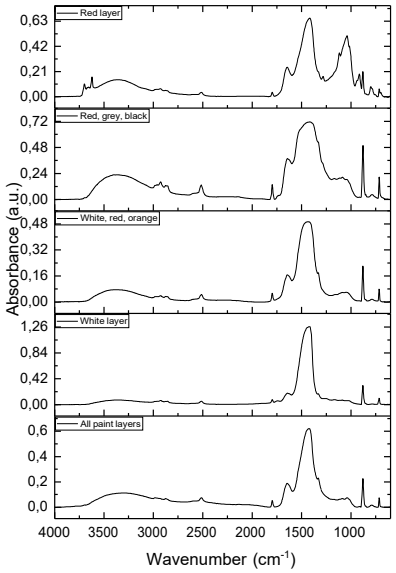
Table S 12: Spectral interpretation of historic paint samples, with assignment of the main absorption bands according to in literature. ν = stretching; νs = symmetric stretching; νa =asymmetric stretching; δ= bending; δs=symmetric bending; δa = asymmetric bend

Compound assignment	Vibrational wavenumber (cm^{-1})	Vibrational mode	Ref. no
Ca sulphates	672	$\nu_4 (SO_4)^{2-}$ δa	[8]
	1619	δ H-O-H	
Calcite (CaCO3)	711 - 2878	$(CO_3)^{2-}$	[9-11]
	~2921-2929	attributed to $2\nu_3$ in dolomite ($MgCaCO_3$) or to organic material (νCH_2)	[10, 12]
Dolomite	1446 sh	$\nu_3(CO_3)^{2-}$	[10]
Quartz	~696	δ_aO-Si-O	[13]
	779 -1153	ν_s Si-O	
	11056sh-1159 sh; 1057-1166	ν_aSi-O	
Clay mineral (Kaolin/ montmorillonites/degraded clays/ amorphous silica)	755	OH translation	[14]
	~788	amorphous silica (ν_s Si-O	[15-19]
	~850	δ OH in Al-Mg(OH)	
	~914	δ OH inner hydroxyl groups / δ Al-O-H (linked to $2Al^{3-}$)	
	~941	δ Al-O-H	
	1010 sh, 1006-1116	ν Si-O	
	~1642, 1162, ~1640	δ H-O-H	
	1642	*C=O + C=C vibrations (aromatic ketones)*/ δ H-O-H	
	~3621	ν OH (inner oxydrils, between the tetrahedral and octahedral sheets)	
	~3657	ν OH out of plane (octahedral surface of layers)	
	~3696	ν_s OH in-phase (octahedral surface of layers))	
General clay minerals	780	amorphous silica (ν_s Si-O)	[15-17]
	~850	δ OH in Al-Mg(OH)	
	1038sh, ~1114	ν Si-O	

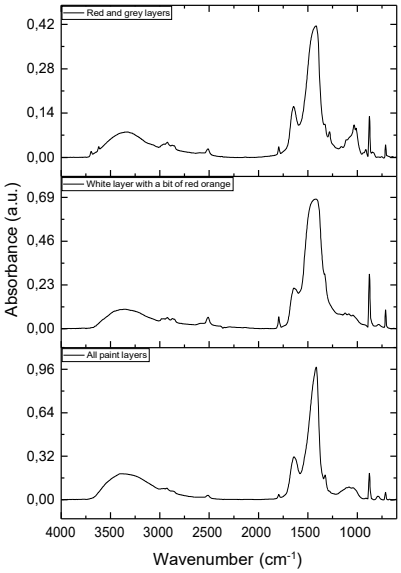
	~1642	δ H-O-H	
wood	902	*In-plane* ν_s *C-H*	[20-22] *[22] indicates as deformation=bending
	~1035	~ ν C-O *	
	~1056	ν *C-O and* ν *C-C*	
	~1116	ν_a C-O-C	
	~1162	ν_a C-O + ν_a C-C	
	~1238	ν C-O in Xylene and syringyl ring	
	~1282	ν C-O in guaiacyl ring + OH and ω CH	
	~1326	Syringyl ring breathing with C=O stretching and C1-O vibration in syringyl derivatives of lignin + C-H vibration of cellulose	
	~1372-1382	δ_s CH_3 groups and δ_a CH_3 groups	
	1421	ν aromatic structure	
	1467sh	δ_a CH_3 in methoxyl groups	
	1511sh	ν aromatic structure C=C	
	1619-1644	δ H-O-H	
	~1643	C=O + C=C vibrations (aromatic ketones)/ H-O-H bending	
	~1731	unconjugated ν C=O in a carbonyl group	
	1741	C=O + C=C vibrations (aromatic ketones)/ H-O-H bending	
	~2851	ν unconjugated C=O related to a carbonyl group	
	~2961	ν C-H	[22, 23]
	~3388, 3400sh	ν O-H	
Pine resin (abietic acid/dehydroabietic acid)	1549	COOH overtones	[24]
	~2591	ν O-H, overtone/combined bands	
animal protein/ animal glue	~1644	ν C=O-N-H + δ NH_2	[19, 25]
	~2873, 2891,2935, ~2985, 2983sh	ν_a CH_3	[19, 25, 26]
	~2921, ~2934, ~2985, 3378	ν CH_2	
	2853	ν_s CH_2	
	3300	ν NH	[25, 27, 28]
	3350, 3366	ν_a NH/ ν CH_2	[19, 26]

linseed oil	669	Unsaturated cycles	[29]
	~711	γ-(C H)	
	721	Rocking (CH2) /cis C=(C-H) out of plane deformation	
	983 sh	trans–trans conjugated ω(C-H)	
	~1158	ν(C-O) in triglycerides ester linkage + ν_a (C-O) of C-CO-O of higher aliphatic esters	
	1234	ν(C-O) in triglycerides ester linkage + ν_a C-CO-O-	
	1372	Deformation CH in methyl/ω(CH_2)	
	~1415	ν C-O in COOH	
	1421, 1708sh	ν(C-O) in COOH	
	1623	(C=C) conjugated	
	~1642	Weak cis C= C	
	1723	ν C=O	
	~1743, 1738sh	ν(C=O) ketones, ester, acid carbonyl	
	~2853	ν_s (CH)- CH_2	
	~2955, 2954sh	ν (CH)CH_3	
	~3004, ~ 3395	ν(CH)-CHCH=CH unconjugated cis double bonds	
	3263, ~ 3341, 3430, 3482, 3538, 3480sh, 3540sh	ν OH	
	797, 1143, 1452	*not attributed*	
cured/aged linseed oil	1172	ν -C(O)-OCH_2-	[29]
	1417	ν C-O in COOH	
	1642	Weak cis C=C	
	2851	ν_s (CH) CH_2	
	2923	$\nu_a CH_2$	
	3350	ν_s OH	[29, 30]

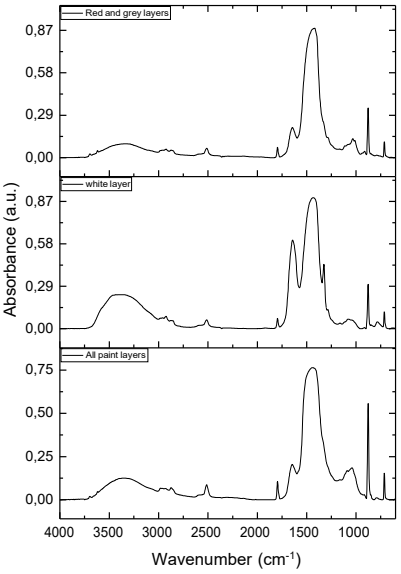
H1a



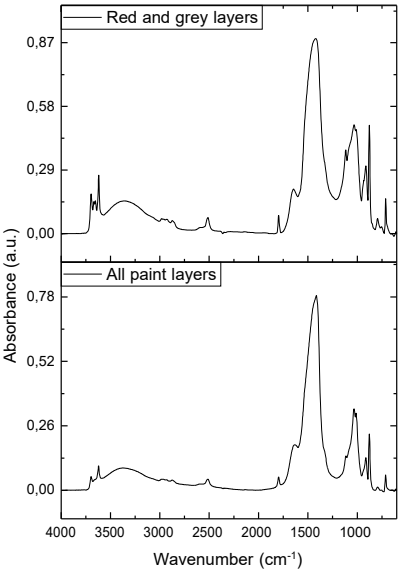
H1b



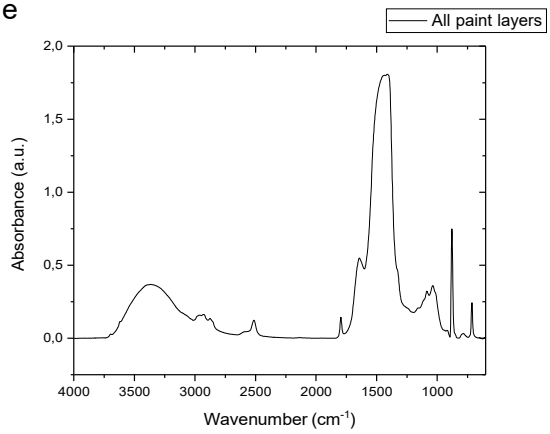
H1c



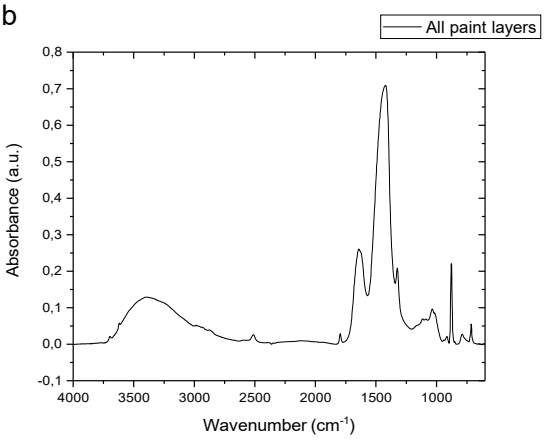
H1d



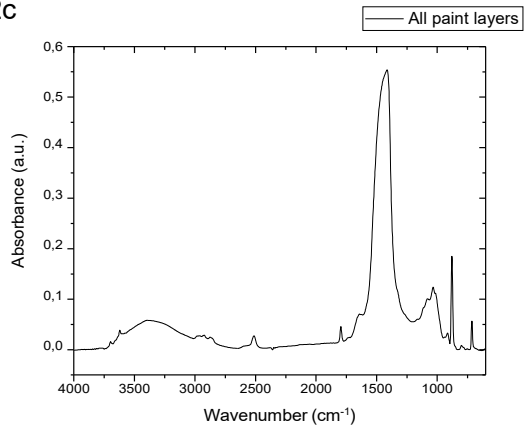
H1e



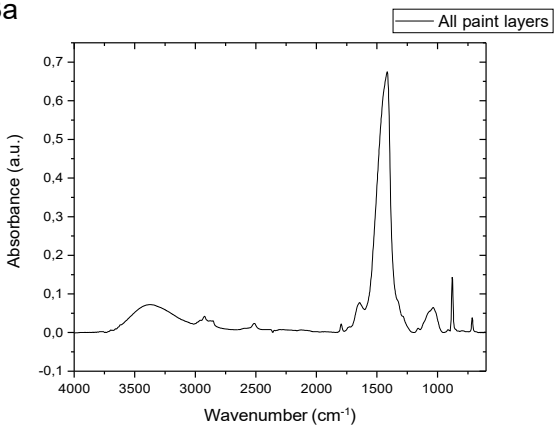
H2b



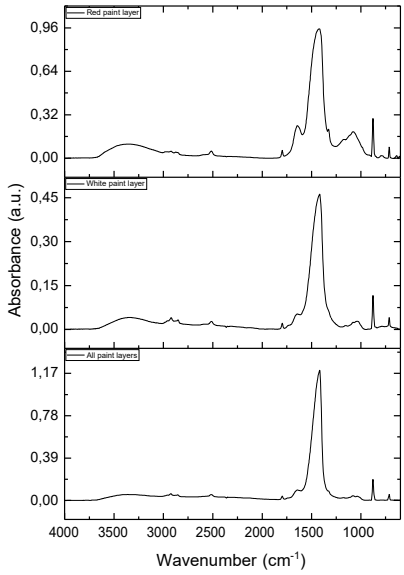
H2c



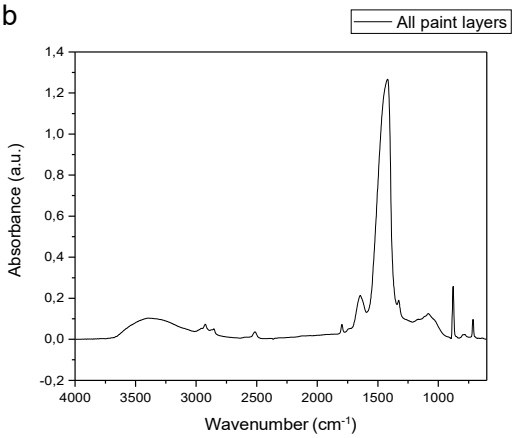
H3a



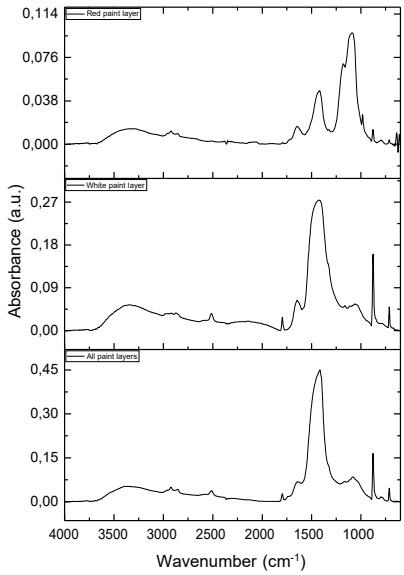
E1a



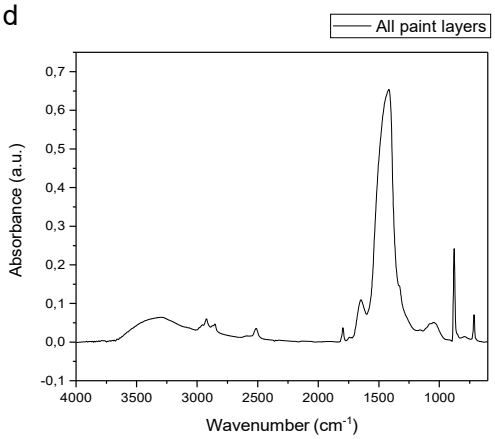
E1b



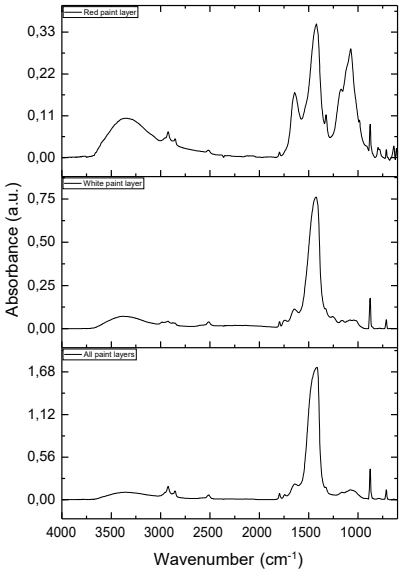
E1c



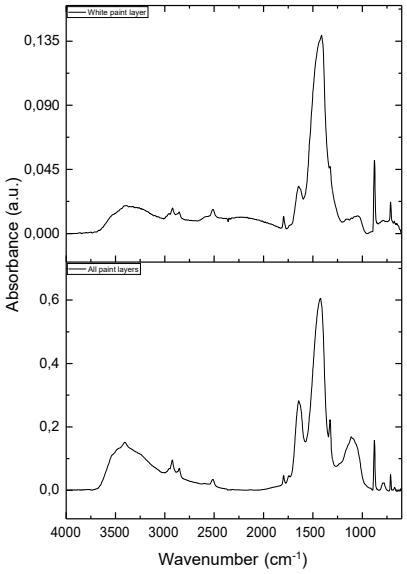
E1d



E1e



E2a



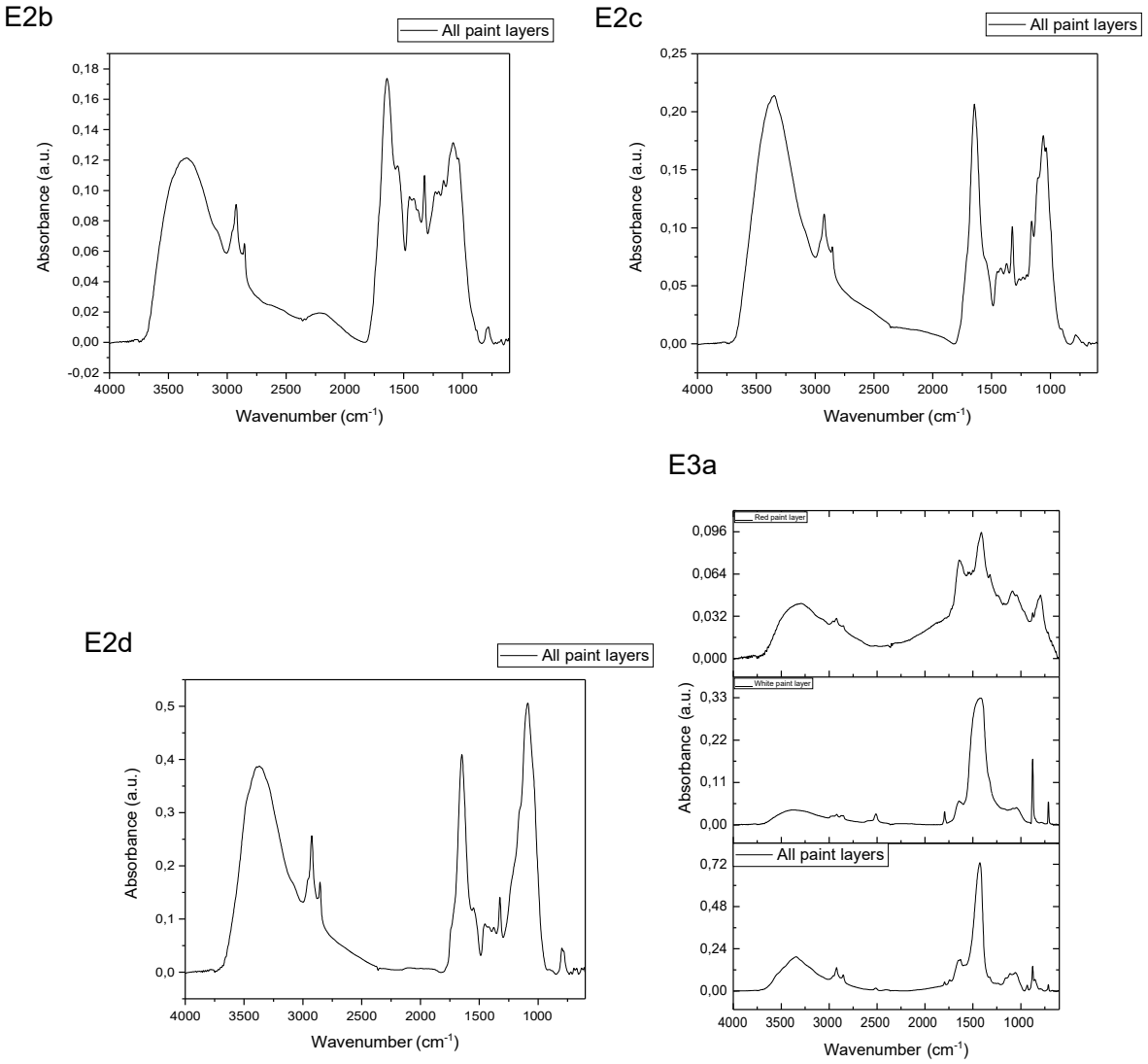


Figure S 6: FT-IR spectrum in the region 4000–600 cm^{-1} for all samples, with layer isolation when possible.

Table S 13: Signals assigned to FT-IR analysis of pigments. See **Table S 12** for attributions and references.

Sample name	Ca sulphates/ gypsum	Calcite	Quartz	Dolomite (CaMg(CO3)2)	Clay mineral (general clay minerals/ Kaolin/montmorillonite/ degraded clays/ amorphous silica)
H1a		711, 877, 1085, 1421, 1793, 2512, 2873			788, 850, 914, 1010, 1035, 1116, 1162, 3696
H1b	672, 1619	713, 877, 1085, 1415, 1795, 2512, 2929	790		1045, 1108, 1640
H1c		713, 877, 1089, 1438, 1795, 2510, 2873	779, 794, 1162		848, 914, 941, 1006, 1037, 1114, 1644, 3621, 3657, 3698

H1d	877, 1081 sh, 1411, 1444, 1795, 2512, 2877	794		755,848, 914, 939, 1008, 1033, 1116, 3621, 3694
H1e	712, 876, 1083, 1409, 1448, 1795, 2850, 2875, 2929	784, 1153		848, 915, 1010 sh, 1035, 1116, 1642, 3617, 3696
H2a	713, 877, 1079, 1403, 1795, 2510, 2873			790, 850, 914, 1008, 1031, 1108, 1641, 3621, 3694
H2b	713, 877, 1089, 1423, 1795, 2512, 2878			786, 848, 914, 937, 1008, 1035, 1114, 1640, 3619, 3698
H2c	711, 877, 1078, 1413, 1793, 2510, 2923	779, 800, 1162	1446? Sh	748, 850, 912, 1010, 1031, 1112, 1644, 3619, 3656, 3696
H3a	713, 877, 1074, 1415, 1795, 2512, 2921			912, 1033, 1112, 1642
E1a	713, 877, 1079, 1417, 1795, 2510, 2923			
E1b	711, 877, 1079, 1415, 1795, 2512, 2875, 2923	780, 800, 1166		780, 850, 1018sh, 1114, 1642
E1c	711, 877, 1081, 1411, 1795, 2510, 2877, 2923	779, 798, 1164		850, 1114, 1644
E1d	711, 875, 1083, 1413, 1797, 2512, 2875, 2923			846, 1110, 1646
E1e	711, 875, 1075, 1413, 1795, 2512, 2923			850 sh, 1116 (low), 1642
E2a	711, 875, 1090, 1421, 1795, 2512, 2923	696, 779, 798, 1056sh, 1164		846, 1112, 1643
E2b	875, 1413, 2875, 2923	779, 800		
E2c				
E2d		695, 781, 794, 1159 sh		
E3a	712, 876, 1426, 1796, 2512, 2922	782, 797, 1057, 1160		851, 1038sh, 1114, 1648

Table S 14. Signals assigned to FT-IR analysis of organic material (wood fractions, animal protein, and linseed oil). See **Table S 12** for attributions and references.

Sample name	Wood	Pine resin (abietic acid / dehydroabietic acid)	animal protein (animal glue/ animal protein)	Linseed oil

H1a	1035,1116, 1162, 1326, 1643		2935, 2985, 3300	
H1b	1108, 1282, 1324, 1619, 1640, 2851, 3388			
H1c	1037, 1114, 1162, 1280, 1328, 1644, 2848, 3355	1644, 2873	1644, 2873, 2891, 2923	
H1d	1033, 1116, 1326, 3374		2934, 2977	
H1e	1035, 1116, 1326, 1642,2961, 3366, 2591	1642, 2875	1642, 2875, 2983, 2929, 3366	
H2a	1108, 1162, 1641, 2967, 3386, 2597		2934	
H2b	1035, 1114, 1160,1326, 1618, 1640, 3388			
H2c	1031, 1112, 1162, 1644, 1730, 2850, 3380, 3397	2875	2875, 2985	
H3a	1033, 1112, 1160, 1280, 1324, 1642, 1731, 2851, 2961,3378	1642	1642,2921, 3378	
E1a	1326, 2851, 3350 (low)	1642	1642, 2923, 3350	
E1b	1114, 1324, 1642, 2853, 2958, 3395	1642	1642, 2923, 2985	669, 711, 1642, 1743, 2853, 2923 (low), 3395
E1c	1114, 1164, 1324, 1644, 1741, 2853,2961, 3351 (low), 3399	1644	1644, 2923, 2986, 3351	
E1d	1045, 1158, 1326, 1741, 2851, 2958, 3320 (low)	1646	1646, 2923, 2986, 3320	711, 1413,1646, 1741, 2851, 2923 (low)
E1e	1047, 1116, 1162, 1324, 1642, 1743, 2851, 2958, 3357 (low)			711, 983 sh, 1413, 1642, 1743, 2851, 2923
E2a	1112, 1164, 1324, 1623, 1643, 1739, 2852, 2954, 3400, 3405, 3430	1643	1643, 2923, 2985	711, 1143, 1228 (low), 1623, 1643, 1739, 2852, 2923 (low), 3263, 3405, 3430, 3430, 3482, 3538
E2b	1035, 1110, 1160, 1228, 1322, 1382, 1467sh, 1640, 1741 sh, 2853, 2958, 3347 (low)			721, 1158, 1234, 1372, 1421, 1645, 1708 sh, 1745sh, 2851, 2924, 2959, 3343
E2c	902, 1035, 1056, 1106,1158, 1234, 1323, 1372, 1421, 1511sh,1645, 1745sh, 2851, 3390			
E2d	903, 1038sh, 1159 sh, 1227sh, 1325, 1376, 1418, 1649, 1738sh, 2854			721, 1159 sh, 1227sh, 1376, 1418, 1649, 1738sh, 2854, 2924, 2954sh, 3009, 3347, 3347
E3a	1038sh, 1160, 1238, 1324, 1648, 1744, 2853,3400sh	1648, 2853	1648, 2853, 2922, 2983sh	1160, 1648,1744, 2853, 2922, 2955,3004, 3341, 3341, 3480 sh, 3540 sh

X-Ray Diffraction

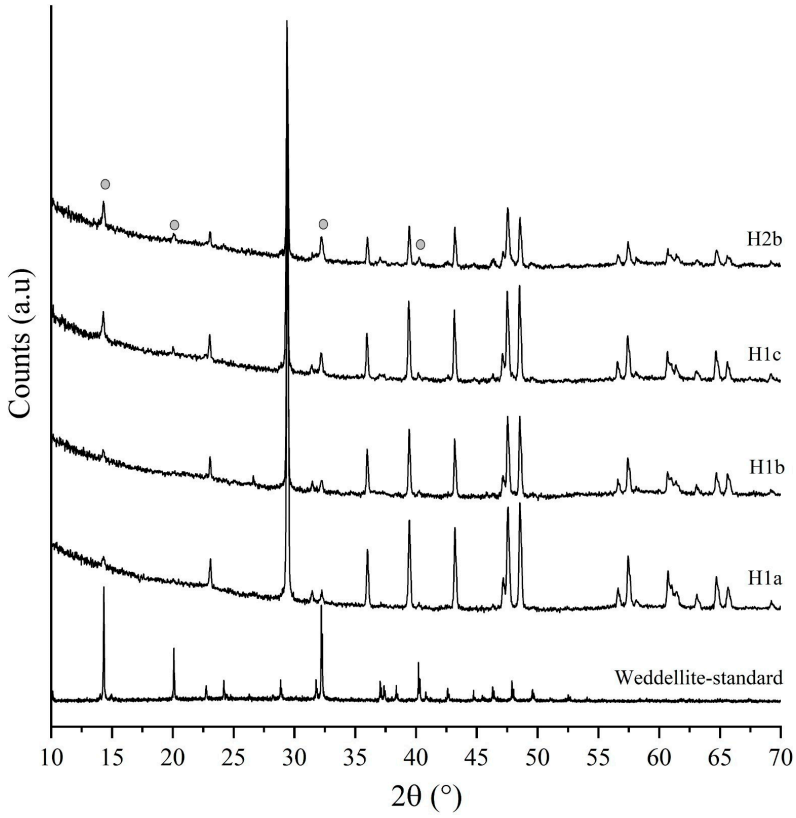


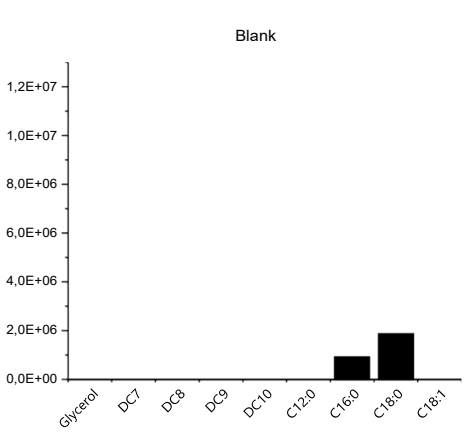
Figure S 7: XRD patterns of samples from Heddal. The intensity increase of weddellite's signals is shown. Considered reflections are marked with a grey dot.

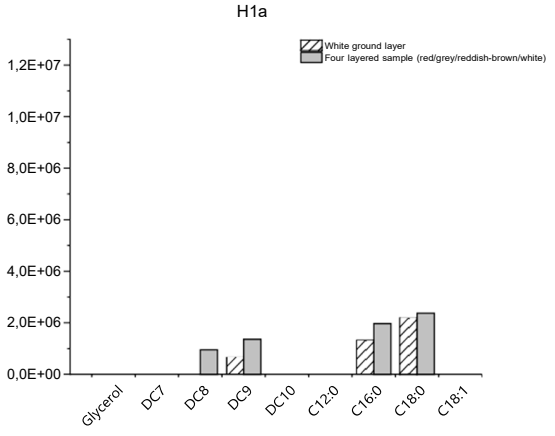
Gas Chromatography-Mass Spectrometry and ELISA

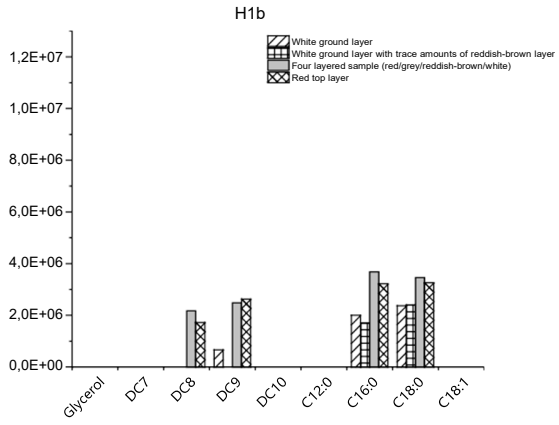
Table S 15: GC-MS testing configuration and parameters

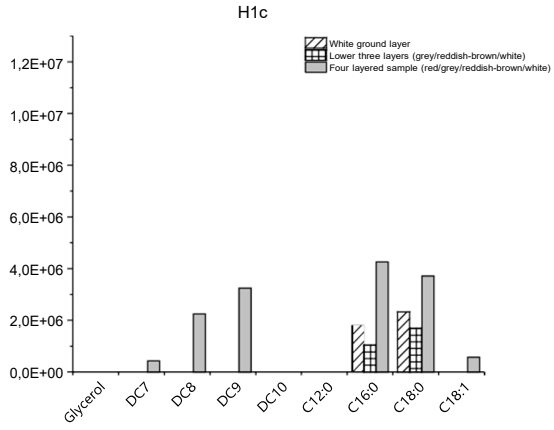
Protocol	Separation column	Oven program
Meth-Prep II: natural plant resins and oils	Zebron™ ZB-5HT (Phenomenex); 30 m x 0.25 mm x 0.10 µm Helium was the carry gas (1.2 mL/min); splitless injection at 300°C and transfer line at 360 °C	80°C for 2 min; temperature was then increased by 10°C/min until 210°C; after which the temperature was increased 20°C/min to 360°C; and lastly the temperature was increase 40°C/min to 380°C.

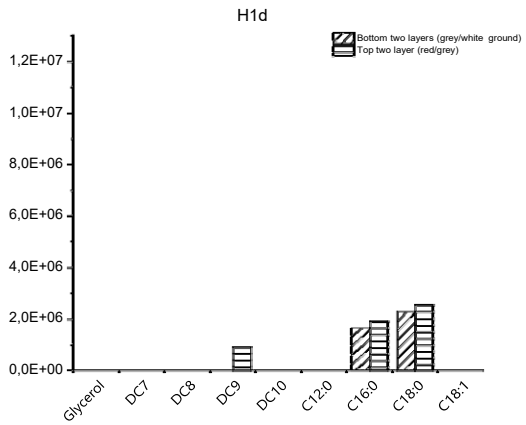
Amino Acid: proteins	INNOWAX; 25 M x 0.2 mm x 0.2µm Helium was the carry gas (1mL/min); splitless injection and transfer line at 240 °C	70 °C for 1 min; temperature was then increased by 20 °C /min until 250 °C; held at 250 °C for 3.5 min.

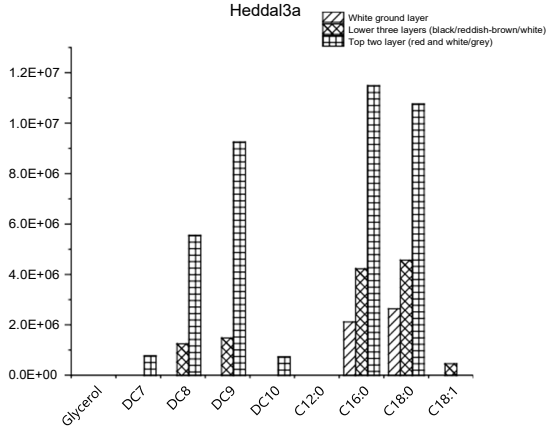


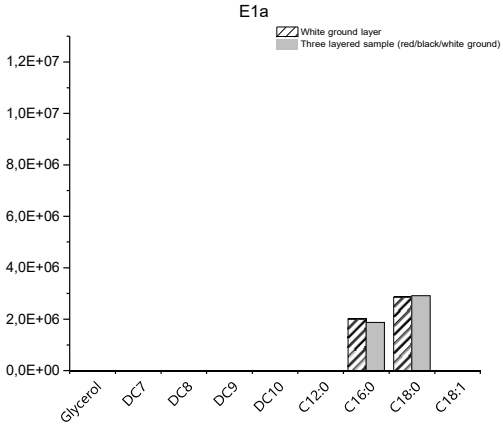


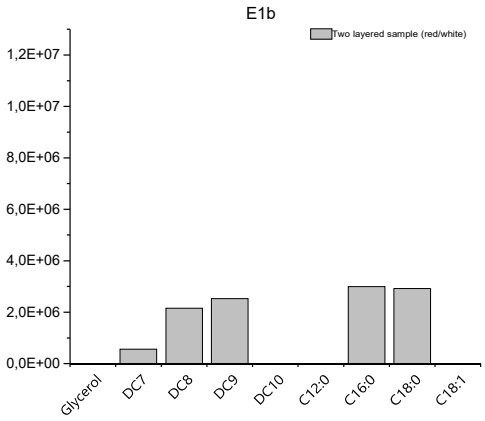


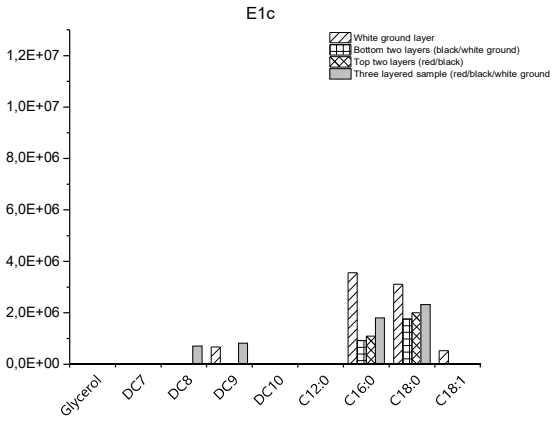


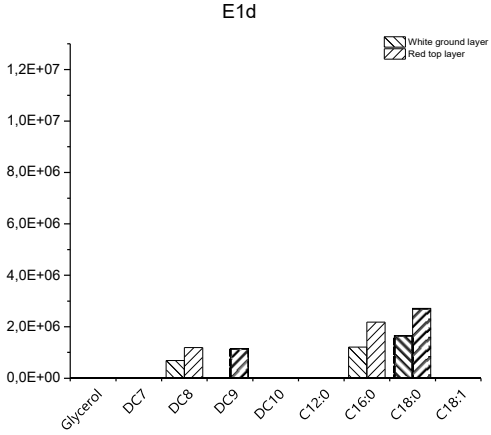


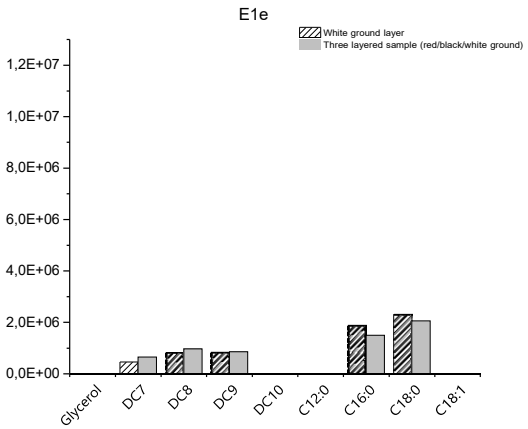


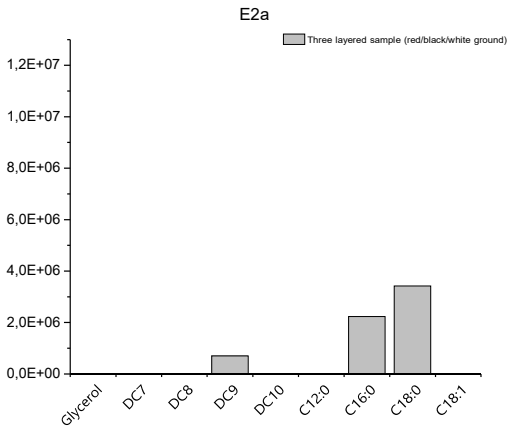

E1a
White ground layer
Three layered sample (red/black/white ground)
1,2E+07
1,0E+07
8,0E+06
6,0E+06
4,0E+06
2,0E+06
0,0E+00
Glycerol
DC7
DC8
DC9
DC10
C12:0
C16:0
C18:0
C18:1


E1b
Two layered sample (red/white)
1,2E+07
1,0E+07
8,0E+06
6,0E+06
4,0E+06
2,0E+06
0,0E+00
Glycerol
DC7
DC8
DC9
DC10
C12:0
C16:0
C18:0
C18:1


E1c
White ground layer
Bottom two layers (black/white ground)
Top two layers (red/black)
Three layered sample (red/black/white ground
1,2E+07
1,0E+07
8,0E+06
6,0E+06
4,0E+06
2,0E+06
0,0E+00
Glycerol
DC7
DC8
DC9
DC10
C12:0
C16:0
C18:0
C18:1


E1d
White ground layer
Red top layer
1,2E+07
1,0E+07
8,0E+06
6,0E+06
4,0E+06
2,0E+06
0,0E+00
Glycerol
DC7
DC8
DC9
DC10
C12:0
C16:0
C18:0
C18:1


E1e
White ground layer
Three layered sample (red/black/white ground)
1,2E+07
1,0E+07
8,0E+06
6,0E+06
4,0E+06
2,0E+06
0,0E+00
Glycerol
DC7
DC8
DC9
DC10
C12:0
C16:0
C18:0
C18:1


E2a
Three layered sample (red/black/white ground)
1,2E+07
1,0E+07
8,0E+06
6,0E+06
4,0E+06
2,0E+06
0,0E+00
Glycerol
DC7
DC8
DC9
DC10
C12:0
C16:0
C18:0
C18:1

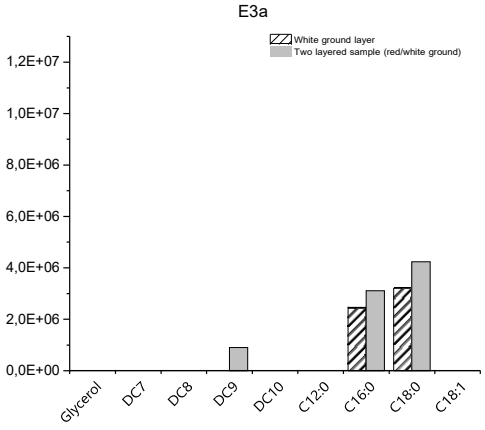


Figure S 8: Monocarboxylic and dicarboxylic fatty acids (lauric(C12:0), palmitic (C16:0), oleic (C18:1), stearic (C18:0), and pimelic(C7), suberic(C8), azelaic(C9), sebacic acids(C10), respectively) and glycerol peaks derived from Meth Prep analysis.

Table S 16: List of amino acid compositions from historic paints samples by GC-MS analysis (parts per million).

Sample location & description		weight, µg	alanine	glycine	valine	leucine	isoleucine	proline	serine	threonine	phenylalanine	hydroxyproline
	White ground layer	226.8	81	222	25	36	21	69	50	53	20	55
E1a	**Three layered sample** (red/black/white ground)	842.3	158	483	42	59	40	164	97	81	37	92
	wood	515.2	179	507	58	113	55	185	155	191	65	130
E1b	**Two layered sample (**red/white ground)	467.6	140	366	61	86	49	139	109	82	45	77
	wood	225.3	91	233	29	46	25	85	72	75	34	61
	White ground layer	289.4	63	213	20	34	20	51	47	60	18	41
	Bottom two layers (black/white ground)	48.0	7	17	2	2	1	6	6	6	2	14
E1c	**Top two layers** (red/black)	131.3	15	34	4	4	3	11	17	19	2	34
	Three layered sample (red/black/white ground)	585.9	121	357	32	43	24	116	72	75	36	89
	White ground layer	581.4	150	460	43	43	29	135	91	109	31	120
E1d	**Red top layer**	194.5	42	89	16	23	12	49	42	39	14	43
	Two layered sample with insect (red/white)	470.0	0	1	0	0	0	0	0	2	0	5
E1e	**White ground layer**	368.5	258	669	55	60	35	175	129	150	42	206

	Three layered sample (red/black/white ground)	683.1	241	684	45	39	26	168	119	172	45	165
E2a	**Three layered sample** (red/black/white ground)	191.9	40	119	11	20	9	39	29	32	16	46
	wood	207.4	69	189	17	8	10	69	33	39	15	80
E3a	**White ground layer**	224.5	52	137	14	17	10	40	46	39	12	53
	Two layered sample (red/white ground)	1114.7	183	694	42	46	24	174	83	90	33	125
	White ground layer	102.1	17	34	5	8	3	14	16	15	4	23
H1a	**Four layered sample** (red/grey/orange /white ground)	511.1	170	417	46	62	31	160	82	85	37	119
	White ground layer	189.0	145	326	42	59	29	133	86	76	34	94
H1b	**White ground layer with trace amounts of orange layer**	123.0	57	129	18	25	13	56	39	36	15	47
	Four layered sample (red/grey/orange /white)	636.6	204	613	60	86	40	248	112	104	52	161
	Red top layer	522.1	55	128	14	24	10	51	41	40	17	61
	White ground layer	123.1	41	119	13	19	9	50	24	25	13	37
H1c	**Lower three layer** (grey/ orange / white ground)	256.9	0	3	0	2	1	0	0	2	0	2
	Four layered sample (red/grey/orange /white ground)	618.2	207	658	61	86	42	303	95	93	58	163
	Bottom two layers (grey/white ground)	392.6	185	693	29	38	20	119	81	86	26	92
H1d	**Top two layer (**Red/grey)	303.2	44	141	11	17	8	38	39	36	12	42
	wood	211.4	35	127	12	16	9	47	61	34	14	53
	White ground layer	116.2	33	70	10	14	8	31	30	21	9	34
H3a	**Lower three layer** (black/orange /white ground)	258.4	111	279	38	56	29	109	78	55	34	68
	Top two layer (red and white/grey)	1069.7	370	1174	94	151	65	522	192	155	97	83

Table S 17: Fatty acid content (ppm) from paint samples analysed, where ND denotes not detected or below the detection limit

	Sample location & description	**weight, µg**	**Pimelic**	**Suberic**	**Lauric**	**Azelaic**	**Sebacic**	**Myristic**	**Palmitic**	**Stearic**	**Oleic**
	Blank vial	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	1,65	2,35	N.D.
E1a	**White ground layer**	226.8	0	0	0	0	0	0	3.62	3.61	0
	Three layered sample (red/black/white ground)	842.3	0	0	0	0	0	0	3.34	3.65	0
	Wood specimen	515.2	4.08	7.11	0	12.07	1.81	0	11.82	11.43	2.22

E1b	**Two layered sample** (red/white)	467.6	1.31	3.21	0	3.89	0	0	5.35	3.66	0
	Wood specimen	225.3	2.09	3.35	0	5.27	0	0	2.73	2.36	0
E1c	**White ground layer**	289.4	0	0	0	1.03	0	0	6.36	3.9	2.15
	Bottom two layers (black/white ground)	48.0	0	0	0	0	0	0	1.65	2.21	0
	Top two layers (red/black)	131.3	0	0	0	0	0	0	1.95	2.51	0
	Three layered sample (red/black/white ground)	585.9	0	1.05	0	1.26	0	0	3.23	2.91	0
E1d	**White ground layer**	581.4	0	1.02	0	0	0	0	2.17	2.08	0
	Red top layer	194.5	0	1.78	0	1.73	0	0	3.9	3.41	0
	Two layered sample with insect (red/white)	470.0	0	0	0	0	0	0	1.63	2.01	0
E1e	**White ground layer**	368.5	1.08	1.21	0	1.31	0	0	3.38	2.91	0
	Three layered sample (red/black/white ground)	683.1	1.53	1.45	0	1.32	0	0	2.68	2.57	0
E2a	**Three layered sample** (red/black/white ground)	191.9	0	0	0	1.07	0	0	3.99	4.28	0
	Wood specimen	207.4	2.57	1.93	0	3.96	0	0	2.85	2.67	0
E3a	**White ground layer**	224.5	0	0	0	0	0	0	4.46	4.03	0
	Two layered sample (red/white ground)	1114.7	0	0	0	1.39	0	0	5.56	5.31	0
H1a	**White ground layer**	102.1	0	0	0	1.03	0	0	2.38	2.74	0
	Four layered sample (red/grey/reddish-brown/white)	511.1	0	1.43	0	2.1	0	0	3.53	2.98	0
H1b	**White ground layer**	189.0	0	0	0	1.03	0	0	3.58	2.97	0
	White ground layer with trace amounts of reddish-brown layer	123.0	0	0	0	0	0	0	3.05	3.01	0
	Four layered sample (red/grey/reddish-brown/white)	636.6	0	3.25	0	3.83	0	0	6.59	4.34	0
H1c	**Red top layer**	522.1	0	2.57	0	4.05	0	0	5.75	4.08	0
	White ground layer	123.1	0	0	0	0	0	0	3.23	2.92	0
	Lower three layers (grey/reddish-brown/white)	256.9	0	0	0	0	0	0	1.86	2.12	0
	Four layered sample (Red/grey/reddish-brown/white)	618.2	1.02	3.36	0	5.01	0	0	7.62	4.66	2.36
H1d	**Bottom two layers** (grey/white ground)	392.6	0	0	0	0	0	0	2.97	2.85	0
	Top two layer (Red/grey)	303.2	0	0	0	1.4	0	0	3.43	3.17	0
	Wood specimen	211.4	0	0.99	0	2.7	0	0	3.49	2.65	0
H3a	**White ground layer**	116.2	0	0	0	0	0	0	3.78	3.31	0
	Lower three layers (black/reddish-brown/white)	258.4	0	1.87	0	2.29	0	0	7.56	5.72	1.88
	Top two layer (red and white/grey)	1069.7	1.8	8.27	0	14.25	1.2	0	20.54	13.49	0

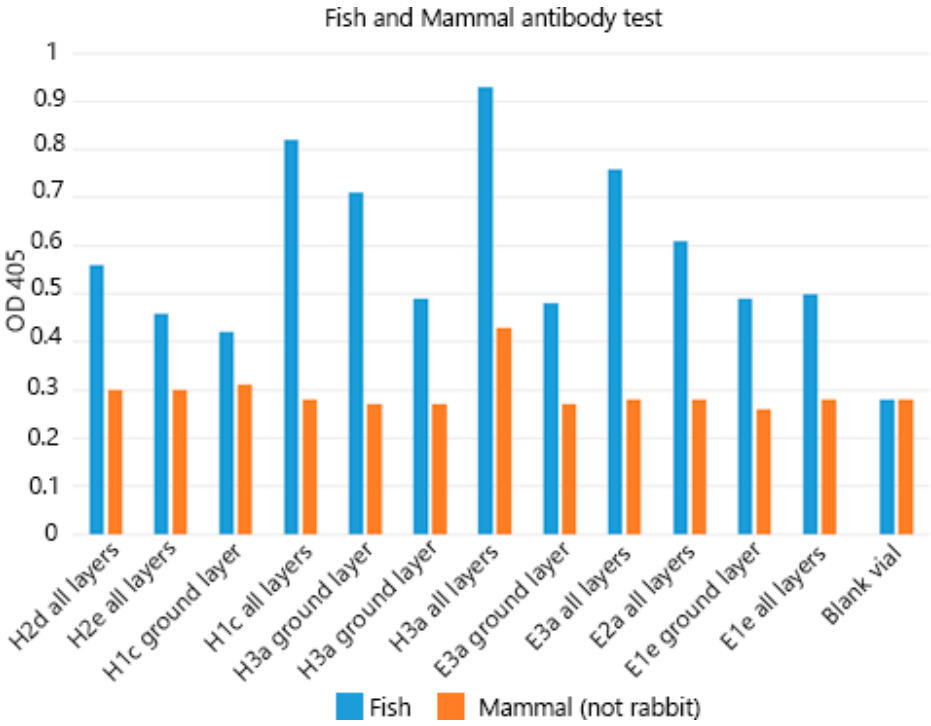


Figure S 9: Chart of plat reading results at OD45, where blue bars are absorbency reading for fish collagen and orange bars are for mammal collagen.

References

1. Olstad TM. To the Glory of God and the Church's Adornment. In: Bakken K, editor. Preserving the Stave Churches Craftmanship and Research: Riksantikvaren; Pax Forlag; 2016.
2. Olstad TM, Solberg K. Eight seventeenth-century decorative paintings-one painter? Studies in Conservation. 1998;43(sup1):175-9.
3. Olstad TM, K. Solberg. Analytical Report, Centre for Art Technological Studies and Conservation (CATS) Copenhagen; 2015.
4. Wedvik B. A 167 Heddal stavkirke. Konsolidering av limfargedekor i koret. Prosjektets del 1: Nordvegg og apsis i koret no 49/2008. 2008.
5. Wedvik B. A 167 Heddal stavkirke. Konsolidering av limfargedekor i skip og sørvegg i koret no. 121/2009. 2009.
6. Solberg K, Norsted T, Spaarschuh C. Eidsborg stavkirke. Konservering av veggmalerier fra 1600-tallet og paneler fra middelalderen no35/2007. 2007.
7. Olstad TM, Ørnhøi AA. Konsolidert limfargedekor i stavkirkene- en oversikt. Vurdering av størlim. Konsolidering av limfarge på tre. Delprosjekt 1, NIKU Oppdragsrapport 62/2014, Oslo, . 2014.
8. Liu Y, Wang A, Freemen J. Raman, MIR, and NIR spectroscopic study of calcium sulfates: gypsum, bassanite, and anhydrite. LPI. 2009:2128.
9. Weir C, Lippincott ER. Infrared studies of aragonite, calcite, and vaterite type structures in the borates, carbonates, and nitrates. Journal of Research of the National Bureau of Standards Section A, Physics and Chemistry. 1961;65(3):173.
10. Gunasekaran S, Anbalagan G, Pandi S. Raman and infrared spectra of carbonates of calcite structure. Journal of Raman Spectroscopy: An International Journal for Original Work in all Aspects of

Raman Spectroscopy, Including Higher Order Processes, and also Brillouin and Rayleigh Scattering. 2006;37(9):892-9.
11. Andersen FA, Brecevic L. Infrared spectra of amorphous and crystalline calcium carbonate. Acta Chem Scand. 1991;45(10):1018-24.
12. Kovač N, Faganeli J, Bajt O, Orel B, Vuk Š. Investigation of sediment samples from the Gulf of Trieste (northern Adriatic) by FTIR spectroscopy. Mater Geoenvi. 2005;52(1):81-5.
13. Müller CM, Pejcic B, Esteban L, Delle Piane C, Raven M, Mizaikoff B. Infrared attenuated total reflectance spectroscopy: an innovative strategy for analyzing mineral components in energy relevant systems. Scientific reports. 2014;4:6764.
14. Frost RL, Vassallo AM. The dehydroxylation of the kaolinite clay minerals using infrared emission spectroscopy. Clays and Clay minerals. 1996;44(5):635-51.
15. Madejová J. FTIR techniques in clay mineral studies. Vibrational spectroscopy. 2003;31(1):1-10.
16. Vaculikova L, Plevova E, Vallova S, Koutnik I. Characterization and differentiation of kaolinites from selected Czech deposits using infrared spectroscopy and differential thermal analysis. 2011.
17. Saikia BJ, Parthasarathy G. Fourier transform infrared spectroscopic characterization of kaolinite from Assam and Meghalaya, Northeastern India. J Mod Phys. 2010;1(4):206-10.
18. Bikiaris D, Daniilia S, Sotiropoulou S, Katsimbiri O, Pavlidou E, Moutsatsou A, et al. Ochre-differentiation through micro-Raman and micro-FTIR spectroscopies: application on wall paintings at Meteora and Mount Athos, Greece. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 1999;56(1):3-18.
19. Ganitis V, Pavlidou E, Zorba F, Paraskevopoulos K, Bikiaris D. A post-Byzantine icon of St Nicholas painted on a leather support. Microanalysis and characterisation of technique. Journal of Cultural Heritage. 2004;5(4):349-60.
20. Moosavinejad SM, Madhoushi M, Vakili M, Rasouli D. Evaluation of degradation in chemical compounds of wood in historical buildings using FT-IR and FT-Raman vibrational spectroscopy. Maderas Ciencia y tecnología. 2019(AHEAD):0-.
21. Timar MC, Varodi AM, Hacibektasoglu M, Campean M. Color and FTIR analysis of chemical changes in beech wood (Fagus sylvatica L.) after light steaming and heat treatment in two different environments. BioResources. 2016;11(4):8325-43.
22. Esteves B, Velez Marques A, Domingos I, Pereira H. Chemical changes of heat treated pine and eucalypt wood monitored by FTIR. Maderas Ciencia y tecnología. 2013;15(2):245-58.
23. Mei Y, Liu R. Effect of temperature of ceramic hot vapor filter in a fluidized bed reactor on chemical composition and structure of bio-oil and reaction mechanism of pine sawdust fast pyrolysis. Fuel Processing Technology. 2017;161:204-19.
24. Beltran V, Salvadó N, Butí S, Pradell T. Ageing of resin from Pinus species assessed by infrared spectroscopy. Analytical and bioanalytical chemistry. 2016;408(15):4073-82.
25. Rosi F, Federici A, Brunetti BG, Sgamellotti A, Clementi S, Miliani C. Multivariate chemical mapping of pigments and binders in easel painting cross-sections by micro IR reflection spectroscopy. Analytical and Bioanalytical Chemistry. 2011;399(9):3133-45.
26. Invernizzi C, Rovetta T, Licchelli M, Malagodi M. Mid and Near-Infrared Reflection Spectral Database of Natural Organic Materials in the Cultural Heritage Field. International Journal of Analytical Chemistry. 2018;2018:16.
27. Azadi Boyaghchi M, Nemati Babaylou A, Mosavi Majd A. Identification of the Stain Structure Caused by Hand Contact on Historical Papers of the Pebdeni Museum of Old Manuscripts, Iran. Journal of Research on Archaeometry. 2017;3(2):31-44.
28. Manzano E, Romero-Pastor J, Navas N, Rodríguez-Simón L, Cardell C. A study of the interaction between rabbit glue binder and blue copper pigment under UV radiation: a spectroscopic and PCA approach. Vibrational Spectroscopy. 2010;53(2):260-8.

29. de Viguerie L, Payard PA, Portero E, Walter P, Cotte M. The drying of linseed oil investigated by Fourier transform infrared spectroscopy: Historical recipes and influence of lead compounds. Progress in Organic Coatings. 2016;93:46-60.
30. Bassas M, Marques A, Manresa A. Study of the crosslinking reaction (natural and UV induced) in polyunsaturated PHA from linseed oil. Biochemical engineering journal. 2008;40(2):275-83.