Journal of Cultural Heritage 77 (2026) 127–139

Contents lists available at ScienceDirect

Journal of Cultural Heritage

journal homepage: www.elsevier.com/locate/culher

VSI: TechnoHeritage2024

Non-invasive characterisation of varnished modern paintings: comparative insights and conservation implications

Laura Homer[a,*], Piotr Targowski[b], Magdalena Kowalska[b], Magdalena Iwanicka[c], Francesca Rosi[d], Laura Cartechini[d], David Buti[e], Haida Liang[f], C.S. Cheung[f], Florence Liggins[f], Patrick Atkinson[f], Raffaella Fontana[g], Emma Vannini[g,h], Irene Lunghi[g,i], Georgios Karagiannis[j], Theodoros Karagiannis[k], Angelica Bartoletti[l], Bronwyn Ormsby[l]

[a] *National Museum of Art, Architecture & Design, P.O. Box 7014, St Olavs Plass, 0130 Oslo, Norway*
[b] *Institute of Physics, Nicolaus Copernicus University in Toruń, ul. Grudziądzka 5, 87-100 Toruń, Poland*
[c] *Faculty of Fine Arts, Nicolaus Copernicus University in Toruń, ul. Sienkiewicza 30-32, 87-100 Toruń, Poland*
[d] *Institute of Chemical Science and Technology-SCITEC of CNR, via Elce di Sotto, 8, 06123 Perugia Italy*
[e] *Institute of Heritage Science-ISPC of CNR, Area della Ricerca di Firenze, Via Madonna del Piano 10, 50019 Florence, Italy*
[f] *ISAAC Lab, School of Science and Technology, Nottingham Trent University, Nottingham NG11 8NS, UK*
[g] *CNR-INO National Institute of Optics, Largo Enrico Fermi 6, 50125 Florence, Italy*
[h] *Department of Physics and Astronomy, University of Florence, Via Sansone, 1, 50019 Sesto Fiorentino FI, Italy*
[i] *Department of Chemistry 'Ugo Schiff', University of Florence, Via della Lastruccia, 3-13, 50019 Sesto Fiorentino FI, Italy*
[j] *ORMYLIA Foundation Art Diagnosis Centre, GR-63071 Ormylia, Chalkidiki, Greece*
[k] *Diagnosis Multisystems, GR-63200 Nea Moudania, Chalkidiki, Greece*
[l] *Conservation Department, Tate Britain, Millbank, London SW1P 4RG, UK*

ARTICLE INFO

Article history:
Received 20 March 2025
Accepted 12 November 2025

Keywords:
Acrylic dispersion resin
Vinyl resin
Waterborne varnish
Norwegian modern art
MOLAB

ABSTRACT

This study presents the results of a non-invasive analytical investigation into eight varnished modern paintings from the Norwegian National Museum, dating from 1966 to 1982. These works, executed in either waterborne acrylic dispersion resin or polyvinyl acetate (PVAc) media, have not been examined before. They form part of a broader research initiative aimed at documenting the use and degradation of synthetic, waterborne varnishes over acrylic and vinyl paints in the context of Norwegian modern art, and the implications for conservation treatments. The eight paintings were examined through the mobile laboratory (MOLAB) platform of the European infrastructure for Heritage Science (E-RIHS). Multiple complementary techniques, including optical coherence tomography (OCT), external reflection infrared spectroscopy (ERIRS), x-ray fluorescence (XRF) mapping and optical micro-profilometry, were employed to identify binders and pigments, assess varnish thickness and distribution and document the layer structure without sampling. The results of a central case study, *Winter Sun*, 1966, by Gunnar S. Gundersen (1921–1983) (MS-02579-2988, acrylic on canvas, 165×110 cm), are presented including characterisation of the layer structure, and identification of the paint and varnish compositions.

Comparative analysis between the case study paintings highlights both prevalences and differences within the materials used, informing material history and artistic practices within the mid-century Norwegian context. This in turn informs conservation approaches to the as-yet unresolved challenge of varnish removal from waterborne modern paints. The findings have the potential to inform the future design of representative mock-ups to test potential varnish removal systems. This multimodal, non-invasive approach offers new tools for understanding artist materials and supports conservation decision-making by clarifying when and how varnish removal may be appropriate.

* Corresponding author.
E-mail addresses: laura.homer@nasjonalmuseet.no (L. Homer), ptarg@umk.pl (P. Targowski), mkowalska@umk.pl (M. Kowalska), miwanicka@umk.pl (M. Iwanicka), francesca.rosi@cnr.it (F. Rosi), laura.cartechini@cnr.it (L. Cartechini), david.buti@cnr.it (D. Buti), haida.liang@ntu.ac.uk (H. Liang), sammy.cheung@ntu.ac.uk (C.S. Cheung), florence.liggins@ntu.ac.uk (F. Liggins), patrick.atkinson2017@my.ntu.ac.uk (P. Atkinson), raffaella.fontana@ino.cnr.it (R. Fontana), emma.vannini@ino.cnr.it (E. Vannini), irene.lunghi@ino.cnr.it (I. Lunghi), g.karagiannis@teemail.gr (G. Karagiannis), theodoros.karagiannis13@gmail.com (T. Karagiannis), Angelica.Bartoletti@tate.org.uk (A. Bartoletti), Bronwyn.Ormsby@tate.org.uk (B. Ormsby).

https://doi.org/10.1016/j.culher.2025.11.007
1296-2074/

1. Introduction

The removal of synthetic varnishes from modern paintings remains one of the most complex and unresolved challenges in conservation practice [1–3]. Varnishing acrylic paintings has long been recommended by paint manufacturers to protect paint films from dirt and mechanical damage and to create an even saturation of colour and gloss [4].[1] Since 1966, nearly all major manufacturers of artists' paints produced a complete line of acrylic dispersion paints, including flat and gloss media used for glazing or for final varnishing [5]. However, the materials used – typically acrylic solutions, or waterborne acrylic dispersions and polyvinyl acetate (PVAc) resins – pose serious difficulties when unwanted change occurs. Such change includes physical and chemical degradation phenomena, namely discolouration, yellowing, increased opacity or milkiness and soft, tacky films that imbibe dirt resulting in a greyish appearance. Consequently, the bright colours, tonal balance and artist's intended visual effect(s) can be obscured. Unfortunately, the solubility of acrylic dispersion paints and varnishes are very similar, if not completely the same, making these coatings extremely difficult to remove without risking damage to the artwork.

To date, there is no appropriate, low-risk solution for the removal of synthetic, waterborne varnishes from acrylic dispersion and PVAc paintings due to swelling of the varnish and paint layers and the undercutting and removal of paint [1–2]. Minimisation of the swelling potential of any paint layer is desirable for all cleaning treatments, and significant research has been carried out into this area through soiling removal tests on unvarnished acrylic paint films [6–13]. However, correspondence with conservators worldwide revealed that most do not attempt removal of the varnish layer, even if it has undergone unwanted change, because of the lack of a suitable varnish removal method that does not risk affecting the paint.[2] This is in addition to the ethical challenges associated with the potential removal of artist-applied varnishes.[3]

This study was designed to provide informative results on the main polymer binders of the ground, paint and varnish layers, as well as the layer structure on a group of representative paintings that would contribute to understanding the above outlined challenge. These eight paintings from the Norwegian National Museum, created between 1966 and 1982, are registered in the museum database as being executed in acrylic paint and all have a visible varnish layer present confirmed by eye (Table 1). None of them have previously been studied from a material science or conservation perspective.

Winter Sun, 1966, by Gunnar S. Gundersen (1921–1983) (MS-02579-2988, acrylic on canvas, 165×110 cm) (Fig.1), was selected for detailed evaluation and presentation in this paper. This painting was selected due to its well documented provenance, the art-historical importance of the artist as a leading figure in Norwegian non-figurative art, the presence of a deteriorated varnish layer and early use of acrylic paints in Norway. The remaining seven paintings are discussed in comparative terms to highlight both similarities and variations in material choices, application techniques and varnish characteristics across the group.

The majority of the eight case study paintings can be described as Concrete, Minimalist and/or Op art [14].[4] The compositions are often geometric, and the colour palettes restrained but dominated by bright tones; there is a focus on non-representational form. Non-figurative art had its breakthrough in Norway in the 1950s[5] and Gundersen was one of the most prominent figures driving this new movement, with distinctive use of form and colour [14]. During a 1950 interview with the art critic Jan Askeland, Gundersen described how "pure colours and shapes work best" and that "when two areas of colour lie next to each other, one will come forth in front of the other[...]This constant oscillation helps to create tension and life in the picture surface – also a sense of space, a kind of vibration, one might say." [15].[6] The minimalist, hard-edge composition of spheres and ellipses of *Winter Sun* embodies these artistic intentions. The shapes were constructed with the help of masking tape and stencils, techniques only possible with fast-drying waterborne paints, which Gundersen was quick to start using. Due to the lack of availability of artist-grade acrylic dispersion paints in Norway in the 1960s,[7] he typically used industrial paints; photographs of the artist in his studio from 1967 show several cans of recognisable brands of waterborne household paints.

2. Research aim

This study aimed to characterise the varnish and paint types of eight modern paintings from the Norwegian National Museum, with a particular focus on *Winter Sun*. The main aim of the research was to gather sufficient technical data to enhance the understanding of material history and practices of varnishing modern paintings in Norway in the mid-to-late 20th-century. This knowledge would assist conservators in developing effective conservation strategies for dealing with waterborne varnishes applied over waterborne paint layers. Using complimentary, non-invasive imaging and spectroscopic methods, including optical coherence tomography (OCT), external reflection infrared spectroscopy (ERIRS), x-ray fluorescence (XRF) mapping and micro-profilometry, the primary objectives were to: (i) identify varnish composition, distribution and degradation; (ii) characterise binders and pigments; (iii) document the layer stratigraphy; (iv) reveal varnish and surface morphology. A secondary objective was to gather relevant data that could inform the design of representative mock-ups for varnish removal trials; these are not included in this paper and will be developed in future work. The results contribute to a growing body of research focused on the conservation of synthetic materi-

[1] See also websites of manufacturers, for example Golden Artist Colors (https://goldenartistcolors.com/resources/varnishing-an-introduction [accessed 01.09.25]); the AIC Wiki page on Varnishing (https://www.conservation-wiki.com/wiki/Varnishes_and_Surface_Coatings:_Introduction [accessed 01.09.25]); and the University of Delaware Materials Information and Technical Resources for Artists (MITRA) Artist Online Forum (https://mitra.artcons.artsci.udel.edu/mitra-board/?wpfs=varnish [accessed 01.09.25])

[2] A questionnaire was shared on the Conservation DistList 18.06.2025 (https://www.culturalheritage.org/discussion/survey-questionnaire-on-the-artistic-use-of-varnish-on-acrylic-and-pvac-paintings), as well as emailed directly to practising conservators worldwide specialising in the conservation of modern and contemporary paintings. The questionnaire requested information about their experiences with varnished acrylic paintings; several responded but only one had ever attempted removal of an acrylic dispersion varnish from an acrylic dispersion painting.

[3] An in-depth ethical discussion around the removal of original, artist-applied varnishes is beyond the scope of this paper but will form a large part of the PhD thesis (University of Oslo) by the first author to which this research contributes.

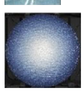
[4] Concrete Art emerged in the 1930s and was the forerunner to Minimalism and Op-art. It prioritises the interaction of geometric forms, colours, and materials and is strictly non-representational. Minimalism developed in the late 1950s and 1960s and is characterised by a focus on form; colours and materials are simple and kept to a minimum. Op Art arose in the 1960s and is distinguished by its use of geometric forms and contrasting colours to produce optical illusions.

[5] Norwegian artists like Bjarne Engebret (1905–1985) had ventured into non-figurative painting during the 1930s but had faced significant resistance and criticism. By the end of World War II in 1945, this pre-war generation of non-figurative painters had largely been forgotten and overlooked. However, a major turning point occurred in 1950 with an exhibition of Concrete art at Kunstnerforbundet in Oslo, marking a significant breakthrough for the movement.

[6] Original text: «Når to fargeflater ligger ved siden av hverandre, vil den ene tre fram foran den andre[...]Denne stadige vekslingen er med og skaper spenning og liv i billedflaten – også en romfornemmelse, en slags vibrasjon kan en kanskje si.». Translated by Laura Homer.

[7] Personal communication with numerous artists living in Oslo in the 1960s and 1970s, including Anders Kjær, Victor Lind and Jørn Nilsen.

Table 1
Overview of the eight case study paintings from the collection of the Norwegian National Museum.

Image	Date	Artist	Title	Materials *(database registration)*
	1966	Gunnar S. Gundersen	Winter Sun	acrylic on canvas
	1972	Per Kleiva	Beams from the Ashes	acrylic on canvas
	1974	Tor Hoff	The Golden Break	acrylic on panel
	1975	Tor Hoff	The Great Heavenly Stone	acrylic on panel
	1980	Anders Kjær	Before the Storm	acrylic on canvas
	1980	Dag Skedsmo	Untitled	acrylic on canvas
	1982	Anna Eva Bergman	Double Mountain	acrylic & silver leaf on canvas
	1982	Marianne Arneberg	Fruit I	acrylic on canvas on panel

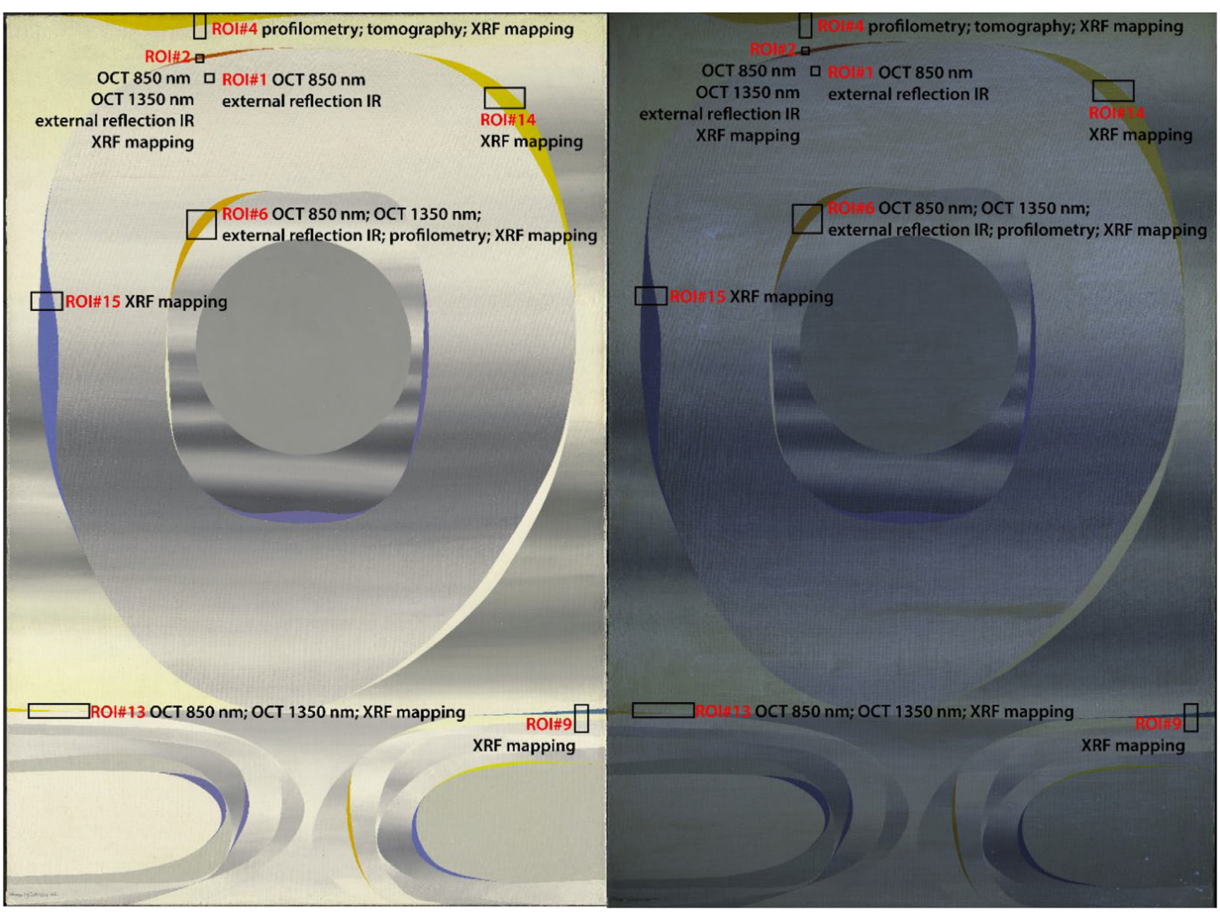


Fig. 1. Overview of the ROIs and locations of analytical measurements on the normal light photograph (left) and the UV photograph (right). Gunnar S. Gundersen, *Winter Sun*, 1966. Acrylic on canvas, 165 × 110.5 cm. MS-02579-1988 © National Museum for Art, Architecture and Design. .

als in modern art and support studies into the ongoing challenge of safely removing aged acrylic dispersion and PVAc varnishes from similarly composed paint films.

3. Materials and methods

3.1. Case study paintings

Initial visual observation of the case study paintings was carried out in normal visible light, both direct and raking, and with ultraviolet radiation (UV). Archival and art-historical research on the paintings and artists provided conservation and art-historical knowledge of these works, which assisted interpretation of the non-invasive analytical data collected by MOLAB. The history and availability of waterborne paints and varnishes within the Norwegian paint market was discovered through examination of the archives of Alf Bjercke AS and Jotun AS, which also contained archival material of several other Norwegian manufacturers during the period of interest.[8] This knowledge provided context for the identified materials. Multiple regions of interest (ROI) on each painting were chosen for data collection and marked on visible light photographs. Where possible, the multiple analytical techniques listed were applied within the same ROIs. The ROI locations for *Winter Sun* are shown in Fig. 1.

3.2. Microscopy

Microscopic examination was carried out using a Leica Wild M80 stereomicroscope (5× to 50× magnification) (Ortomedic AS, Lysaker, Norway). More in-depth evaluations of the varnished surfaces and topographies were possible with the museum's Hirox HRX-01 3D digital microscope (HR-2500E, 20×–2500× revolver zoom lens) (Hirox Europe, Limonest, France). The lens was fitted to a special-made, table-top bridge stand (JAAP Enterprises) enabling examination with the paintings upright on an easel. Images were processed using the in-built HRS-3D software.

3.3. Portable x-ray fluorescence spectroscopy (XRF)

Elemental analysis of inorganic pigments and fillers was carried out after the MOLAB access using the museum-owned portable XRF spectrometer. XRF spectra and elemental maps were captured using a portable Elio ED-XRF spectrometer from Bruker. The system consists of a 4 W rhodium X-ray tube with 50 kV maximum voltage and 0.2 mA maximum working current, and a silicon drift detector (SDD, 25 mm^2 active area, 1 mm collimator, and energy resolution <140 eV measured on Mn Kα line (5890 eV) with 200,000 counts per second (cps) input photon rate, <150 eV at Mn Kα at 500,000 cps). The working distance between the painting surface and the detector is 8-10 mm. When mounted on a tripod with a motorized XY stage, the Elio allows for XRF mapping of an area up to 10 cm^2 in size enabling more precise pigment identification and distribution through spatially resolved elemental detection. The spectra were captured in mapping acquisition mode using the in-built Elio software with a tube voltage of 50 kV and current of 80 µA, and a measuring spot size of 1 mm. The acquisition time was 1 s/mm^{-1}. Spectra and maps were processed using ESPRIT Reveal, Bruker's high-functioning data analysis software designed for art and conservation.

[8] Alf Bjercke AS archives are held at the Norwegian Technology Museum, Oslo (Archive Number: A-1082 - Alf Bjercke). These archives were visited in May 2023. Jotun AS archives, including those of Fleischers, Denofa Lilleborg and additional material from Alf Bjercke AS, are held at Vestfoldarkivet, Sandefjord (Archive Numbers: A-2939 - Pa 1656 - Jotun AS; A-2942 - Pa 1659 - Fleischers kjemiske fabrikk; A-2941 - Pa 1658 - Denofa Lilleborg; A-2940 - Pa 1657 - Alf Bjercke). These archives were accessed in February 2025.

3.4. External reflection fourier transform infrared (FT-IR) spectroscopy (ERIRS)

Single-point non-contact ERIRS was performed in both the mid- and near-infrared ranges (8000–400 cm^{-1}) for the chemical analysis of the paint and varnish media. This method has been successfully used in the past for a broad class of polymer binders, such as acrylic and vinyl resin [16]. Mid-infrared light is absorbed more effectively by the surface layers than near-infrared light, thereby providing information about the coating. Near-infrared has lower absorption in the surface layers and can penetrate deeper, revealing information about subsurface layers, in this case the paint and ground layers [16–17].

The ERIRS analysis was performed with a Bruker Optics portable ALPHA II spectrometer. It works with an optical layout of 22°/22°, collecting the infrared radiation reflected from a surface located at about 1 cm distance through an external reflection module. The probed area is of ca. 6 mm in diameter. Background correction was performed by collecting the total reflectivity, R, from a gold mirror plate. Spectra were recorded in reflection-mode with a spectral resolution of 4 cm^{-1} using 186 scans and expressed as pseudo-absorbance [A'=log(1/R); R= reflectance] spectra.

3.5. Optical coherence tomography (OCT)

OCT is an interferometric technique that employs broadband infrared light. It reveals information about subsurface microstructures such as stratigraphy and layer thickness, through depth-resolved, non-invasive imaging of materials that either weakly scatter or weakly absorb the light at the operating wavelength. It is widely demonstrated as highly suitable for the examination and assessment of transparent and semi-transparent layers in paintings, such as varnishes and glazes [18–20].

Two optical coherence tomography (OCT) systems with central wavelengths of 850 nm and 1350 nm were employed for examination of the structure and thickness of varnishes, and identification of possible isolating or intermediary layers. OCT at 850 nm has high contrast but reduced penetration depth, while OCT at 1350 nm provides images with larger penetration depth as scattering is reduced at the longer wavelength but, consequently, also gives lower contrast images.

3.5.1. OCT at 850 nm

The laboratory-assembled mobile instrument developed at the Institute of Physics of NCU in Toruń used in this study employed a super luminescent source providing broadband illumination [21]. The output of the interferometer was fed into the Cobra CS800–840/180 spectrometer from Wasatch Photonics, USA. In this study, an area of 10 × 10 mm^2 was scanned in 100 parallel lines, comprising 3 000 measuring points each. This data was used for the reconstruction of the surface profile and rendered with colour from the built-in camera's photo. Every one of those 100 scans can be also analysed as a cross-section after correction for a refractive index of the medium (n_R=1.5). The axial resolution of this instrument was 3.3 µm in air and 2.2 µm in varnish (n_R=1.5). The lateral optical resolution was 12 µm. The power of radiation at the object was about 1 mW and fluence 30 mJ/cm^2. The examination time of one 10 × 10 mm^2 area was about 6 s. The distance to the object from the most protruding element of the instrument was 43 mm.

3.5.2. OCT at 1350 nm

The laboratory-assembled mobile instrument developed by the ISAAC Lab used in this study utilises a NKT Photonics SUPER K

EXTREME EXU-6 Super-Continuum light source to provide broadband illumination for a spectral domain OCT system based on a free space Michaelson interferometer and Wasatch Cobra 1300–1300/400 spectrometer. The axial or depth resolution in varnish was 3.3 µm assuming a refractive index of 1.5. The lateral optical resolution was 5 µm. The OCT system produced a volumetric data cube of dimensions 5 × 5 × 1.5 mm through a raster scan of 500 × 500 depth profiles resulting in an overall data cube resolution of 10 × 10 × 5 µm (Width × Length × Depth) in air. The power incident on the object was about 1.5 mW and the fluence was about 15 mJ/cm^2. The working distance was 40 mm.

3.6. Optical micro-profilometry

Optical micro-profilometry provided various 3D models of the paintings' surfaces. A simulated raking light image allowed for visual analysis of the painting surface, akin to regular raking light illumination. 3D maps provided quantitative analysis of surface characteristics, such as canvas texture, air bubbles in the paint layer, sequence of paint layering and accumulation of the paint along the edges of the fields. Large areas can be mapped, yielding spatial and representative surface information as compared to spot areas with microscopy.

The optical micro-profilometer used was a laser scanning device developed at CNR-INO. The instrument is made of a commercial probe (ConoPoint-10 by Optimet, Jerusalem, Israel) mounted on two motorised high-resolution (0.1 µm precision) linear stages that are perpendicularly assembled. The maximum scanning area is 30 × 30 cm^2 and the scanning speed ranges from 100 to 400 points s^{-1} depending on the acquisition parameters. The probe can be equipped with a set of lenses with different focal lengths, resulting in different spot sizes, working distances and resolutions. In this work, the 50 mm lens was used, which provides a spot diameter (at beam waist) of 37 µm, a working distance of 44 mm, and a dynamic range of 8 mm. The reproducibility is 1 µm and the overall accuracy is 6 µm. A sampling step of 50 µm was set in both X and Y directions for all the selected ROIs. The instrument's output is a high-resolution topographic map that can be displayed as a 3D model (.ply format) or as a colour-/grey-scale image. In this work, a set of profiles from each scanned area was extracted in a MATLAB environment, and the thickness of the paint layers was calculated with respect to the base value. The mean thickness values were calculated along with the standard deviation for each layer.

3.7. Ultrasonic tomography

Ultrasonic tomography works in the same way as ultrasound imaging in the medical field, producing real-time images based on sound waves. With operating frequencies of 32–50 MHz, the technique provides stratigraphic information of the artwork and can identify structural defects within and between layers, often at a depth of a few hundred micrometres up to a centimetre, as well as permeability in a preparation layer, if any [22–26]. A dry-contact ultrasonic probe was used, with a single element broadband transducer 32–80 MHz, with a spot size of 15–55 µm and a scanning distance of the transducer inside the probe of 16 mm. The acquisition of measurements was taken in situ and in real time. The scanning results in a set of A-scans that produce cross-sectional tomographic images, alongside B-scans and planar C-scans. Given the identification of acrylic dispersion resin varnish (see Section 4. Results and Discussion), the acoustic velocity for scaling the ultrasonic tomography data was set to 2560 m s^{-1} [27–28].

4. Results and discussion: *Winter Sun*, a model for comparative analysis and insights

4.1. Condition of winter sun

Winter Sun has a clear, glossy varnish layer applied on top of the multi-layered paint. The overall condition of the painting is sound; the paint layers are stable with no visible losses and only minimal cracking along the fold edges. However, the varnish has visibly and unevenly yellowed and has imbibed dust, dirt and fibres. As a result, the bright colours and crisp lines of the composition are visually muted and the artist's intention of space and "oscillation" is somewhat compromised.

4.2. Ground and paint layers: composition and application technique

A matte white ground layer is visible along the fold edges of the linen canvas. It is unevenly applied, extends only slightly onto the tacking edges and comes through to the reverse in some localised spots, suggesting it is artist-applied. The ground layer is completely covered on the front surface by subsequent paint layers. ERIRS in the near-IR range identified the ground as a PVAc vinyl-based resin (ROI#1, IR spectra not shown). The dominate pigment is titanium white, with extenders of talc (hydrated magnesium silicate), kaolin (aluminium silicate), and calcium carbonate (calcite form), also identified with ERIRS.

Archival evidence supports the hypothesis that this may correspond to Jotaplast, an industrial, vinyl-based emulsion produced by Jotun AS, one of the largest Norwegian paint manufacturers at the time. In a product brochure, printed around 1973, Jotaplast is described as a matte "PVA-copolymer emulsion paint for interior use", such as ceilings and priming layers on interior walls.[9] A 1979 recipe lists both kaolin and talc as extender ingredients.[10] Similar ground compositions were found in six of the eight case study paintings (see Table 2), indicating a shared preference by these Norwegian artists for cheap, industrial materials for the priming layers. Indeed, Anders Kjær (see Table 1) has documented his use of Jotaplast on *Before the Storm*, 1980.[11]

The painted forms in *Winter Sun* were built up in multiple layers once each underlying layer was dry. Examination under raking light revealed the layering system and raised edges along each shape, the result of using masking tape and stencils, indicative of a planned and geometric application process. Digital Hirox microscopy revealed details such as surface texture and overlapping of different passages, for example the relatively transparent yellow paint applied over the grey in the lower left (ROI #13). Optical micro-profilometry detailed this creative process more thoroughly through reconstruction of the paint layering sequence. This was achieved by calculating the overall paint layers' thickness from profiles extracted across different layers of pictorial materials (Fig. 2). In the figure, 'Base' refers to the background paint layer, which is the thinnest layer measured in this area. The ground layer lies below this layer and is not included in the images and calculations. Layer 2 is the thickest layer, measuring between 75–110 µm, indicating this was painted on top of all the other layers.

The paint medium was identified with ERIRS in the near-IR range as predominantly vinyl-based, with possible acrylic content

[9] Jotun Archive Pa 1656- Jotun AS, Fbb – L0001, Products: Paint systems, undated (but printed soon after Jotun AS bought out three of the other large paint manufacturers in 1972)

[10] Jotun Archive Pa 1659- Fleischers kjemische fabrikk, F – L0001, Recipes, 1978 – 1982; Recipe 4746, Jotaplast 03, recipe code 065000, 1979

[11] Information gathered directly from the artist upon acquisition of *Before the Storm*, in 1981 and recorded in the document *Informasjon fra kartotek "Materialbruk i moderne malerier i Nasjonalgalleriets eie"*. The document is stored in the museum database.

Table 2
Summary of non-invasive analytical results from Winter Sun.

Layer	XRF mapping	ERIRS	OCT	Optical Micro-profilometry Surface topology	Acoustic Tomography Total number of layers	Tentative assignment
	Elements[a]	Characteristic bands (wavenumber, cm^{-1})	Number, thickness of varnish layers			
Ground	Point analysis: **Ti, Ca**, Zn, Fe, Si	PVAc resin[b] CH+C=O: 4680 cm^{-1} C–H stretch: 4340, 4030, 3970 cm^{-1}	N/A	N/A	N/A	Binder: Vinyl dispersion copolymer Pigments: Titanium white, zinc white. Extenders/inerts: kaolin, talc.
Paint	Yellow: **Cd, Ca, S,** Cl, Ba Blue: **Ti, Ca, S,** Zn, Fe, Si White/cream: **Ti, Ca, K,** Fe, Zn, Si, *S, Ni* Dark turquoise: **Co, Cu, S,** Sr, Br, *Ni, Ba, Cl* Red: **Ca,** Cl	PVAc resin CH+C=O: 4680 cm^{-1} C–H stretch: 4340, 4030, 3970 cm^{-1}	N/A	Canvas texture visible. Ridges of paint formed along edges of painted shapes evident. Order of application visible in raking light.	Overall thickness (including paint): 40 μm. 5 layers can be observed.	Binder: Vinyl dispersion copolymer Pigments: titanium white, zinc white, cadmium yellow, synthetic organic red, ultramarine, cobalt blue?, phthalocyanine blue?, iron oxide pigments. Extenders/inerts: calcite, barium sulfate, and talc.
Varnish	N/A	EA/MMA acrylic[c] C–H stretch: **2985**, 2954 (shoulders 2912, 2880) C=O stretch: **1733** C–H bend: **1465**, 1449, **1383** C–O–C stretch, C–O stretch & C–C stretch: **1239, 1178,** 1162 C–H rock: **854**, 761	Single layer 4–45 µm Air bubbles visible		Thickness of the varnish ~5 μm.	Binder: acrylic dispersion, possibly EA/MMA

[a] bold indicates major elements, no formatting indicates minor elements, italics indicates trace elements.
[b] characteristic FTIR bands for PVAc resin copolymer taken from Rosi et al. [16].
[c] characteristic FTIR absorptions of EA/MMA acrylic dispersion taken from Learner, 2004 [29]. Bold indicates the absorption peaks seen in spectra from Winter Sun.

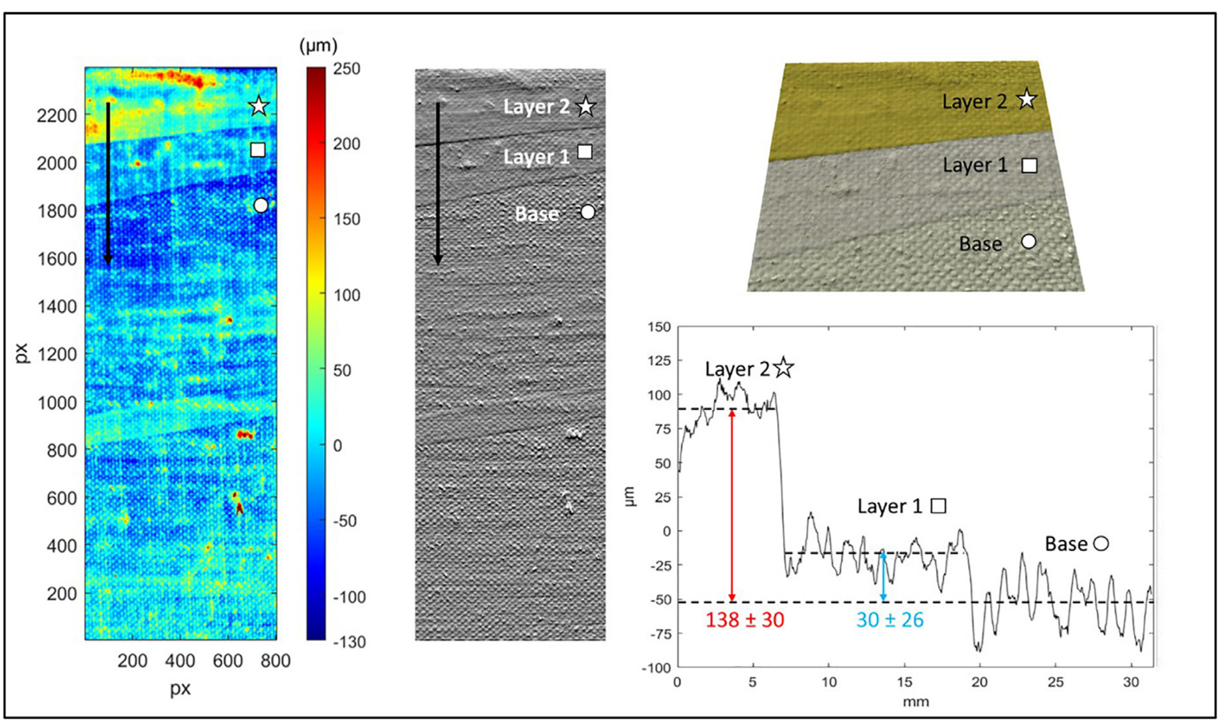


Fig. 2. Optical micro-profilometry of ROI#4 on Winter Sun, showing the colour-coded topographic map (left), the raking light image (centre), and the 3D model with texture (upper right). An extracted profile from which the paint layers' thickness was calculated across different layers of pictorial materials is shown lower right; from this it was possible to deduce the sequence of paint layering. The ground layer is not seen in this ROI and 'Base' refers to the background paint layer. .

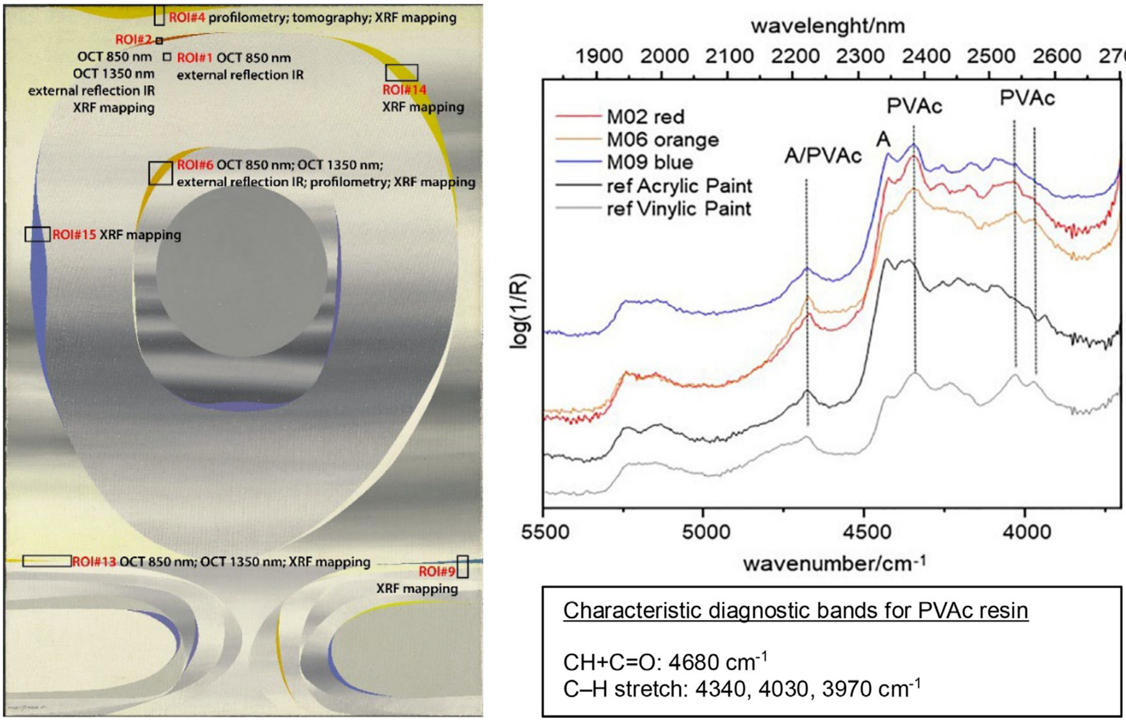


Fig. 3. Left: Winter Sun ROI location map. Top right: ERIRS spectra recorded on Winter Sun ROI#2 red, ROI#6 orange and ROI#9 blue compared with two reference profiles of PVAc (grey line) and acrylic (black line) paint binders. Labels PVAc and A indicate vinyl and acrylic compounds, respectively. The spectra indicate a vinyl paint in all the points, possibly with some acrylic in the red and blue. Lower right: list of characteristic diagnostic bands for PVAc resin in this region (3750–5500 cm^{-1}) [16].

in select red and blue areas (Fig. 3). As mentioned in the introduction, Gundersen often used household paints due to lack of availability of artist-grade products at the time. Photographs of Gundersen in his studio in 1967 show several cans of what can be recognised as Strax, a waterborne emulsion paint for interior house painting, made by Jotun AS since 1962. In a price list dating from 1964, Strax is described as a vinyl-acrylic interior paint[12], supporting the interpretation that at least some passages of paint could be a vinyl-acrylic copolymer.

XRF mapping revealed a consistent pigment palette across the painting. Titanium white (TiO_2) was present in all sample locations, as was calcium carbonate ($CaCO_3$). It is inferred that both white pigments are present in the ground layer and paint layers, as pigment and extender respectively. Barium and sulfur were detected in the white and cream background passages, as well as the turquoise in ROI#9 (Fig. 4 bottom), indicating the presence of barium sulfate ($BaSO_4$) extender in these areas. The yellow shapes in ROI#4 (Fig. 4 top) and ROI#6 were identified as containing cadmium yellow (CdS), possibly with some cadmium red (CdS(Se)) in the darker passages due to the presence of cadmium, sulfur, and selenium. However, neither cadmium nor selenium were detected in the red arc visible in ROI#2. Only calcium (Ca) and chlorine (Cl) were detected (Fig. 4 top), suggesting the presence of a synthetic organic red pigment.

The spatial elemental detection of both cobalt (Co) and copper (Cu) in the dark turquoise line (ROI#9) suggests the use of both a cobalt-based blue and a copper-based blue (Fig. 4 bottom), thought to be copper phthalocyanine blue ($C_{32}H_{16}N_8Cu$). However, while XRF allows detection of copper, it is unable to detect light elements such as carbon, hydrogen and nitrogen, which are characteristic of the phthalocyanine molecule. Therefore, conclusive identification would require analysis with Raman spectroscopy [30]. Nevertheless, given the date of the painting it is most likely to be a copper phthalocyanine blue, which has been described as the most important and widespread artists' blue pigment in the 20th and 21st centuries [31]. In support of this theory, a recipe for another Jotun AS industrial paint from 1976 includes the pigment Heliogen® Blue 6920, which is a strong phthalo blue pigment.[13]

4.3. Varnish characterisation and stratigraphy

Visual and UV observation show a thin but visible varnish layer. It appears to be applied overall, in a relatively uneven layer, most likely with a thick brush when the painting was upright. The varnish has imbibed dirt and yellowed, most evident in the palest areas and where the resin has accumulated in the troughs of the canvas weave. Both OCT systems identified one single layer of varnish on *Winter Sun*, varying in thickness across the surface from 4 to 45 µm (Fig. 5). The thinnest areas tend to be on top of paint layer peaks, while the thickest accumulations were observed along the raised edges of the painted forms, where the varnish has pooled due to uneven surface texture.

The increased penetration into the paint layer provided by OCT at 1350 nm revealed an unexpected intermediate transparent layer between two paint layers (ROI#2; Fig. 6). A thin clear layer (arrow 2) is visible below the red paint, suggesting the white paint was applied and coated with a varnish or layer of acrylic dispersion medium before the red paint was applied and a final varnish layer applied over the entire surface. The purpose of this intermediate layer remains uncertain; it could be a standard practice of

[12] Archive Pa 1656- Jotun AS, Salg, 1943 – 2007, G – L0002, 1964 Pricelist

[13] Jotun Archive Pa 1659- Fleischers kjemische fabrikk, F – L0001, Recipes, 1978 – 1982; Recipe 3020, Bengalac Standardgrønn, recipe code 301078, 1976. Reference to Heliogen Blue pigment: https://colormaterials.sunchemical.com/by-product/products/312/heliogen-blue-l-6920/?i=coatings [accessed 07.08.2025]

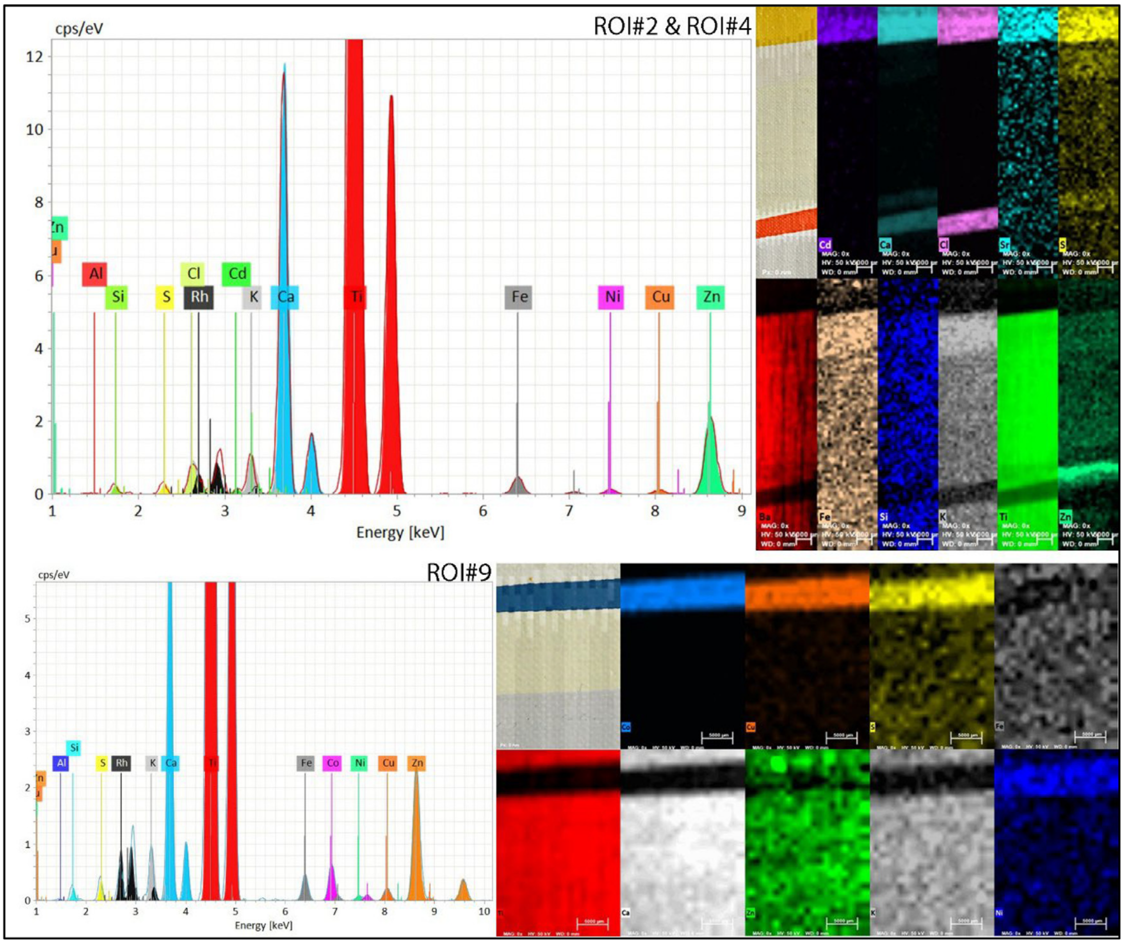


Fig. 4. XRF spectra (quantification view) and maps, tube voltage = 50 kV, tube current = 80 µA, pixel time = 1 sec. Top: ROI#2 and #4 (covered by the same mapping area). The upper yellow passage contains cadmium (Cd), calcium (Ca), sulfur (S), chlorine (Cl) and barium (Ba). Only Ca and Cl are detected in the red stripe, suggesting a synthetic organic pigment. Bottom: ROI#9. The dark turquoise stripe contains cobalt (Co), copper (Cu), and sulfur (S). The cream and grey background passages of both ROIs are dominated by titanium (Ti), calcium (Ca), and potassium (K), with some presence of zinc (Zn) and iron (Fe).

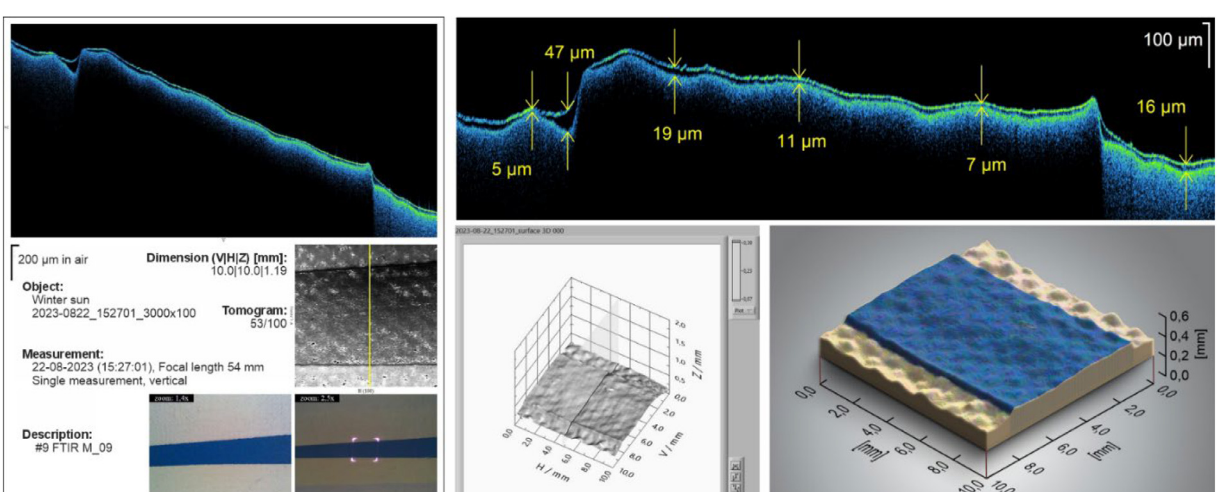


Fig. 5. OCT 850 nm of ROI#9 on Winter Sun showing a single varnish layer, with varying thickness. Upper left: collected tomogram. Lower left: instrument settings and location of data collection. Upper right: processed virtual cross-section (tomogram), corrected for refractive index $n_R = 1.5$, with measurements of varnish layer thickness. Lower centre: processed 3D surface model. Lower right: processed 3D surface model rendered with colour.

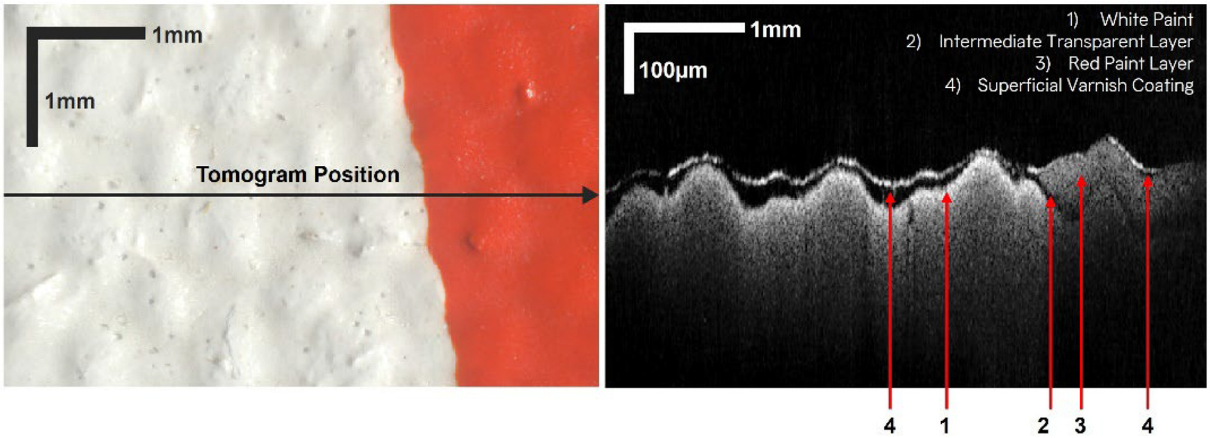


Fig. 6. OCT at 1350 nm, ROI#2, Winter Sun, showing an intermediate varnish layer (arrow 2) below the red paint (arrow 3) with another varnish layer on top (arrow 4). Left: colour image of the scanned region. Right: a virtual cross-section image from the co-aligned 1350 nm OCT. To obtain a physical thickness of coatings and paint layers, the measured thickness from the image needs to be divided by the refractive index $n_R = 1.5$.

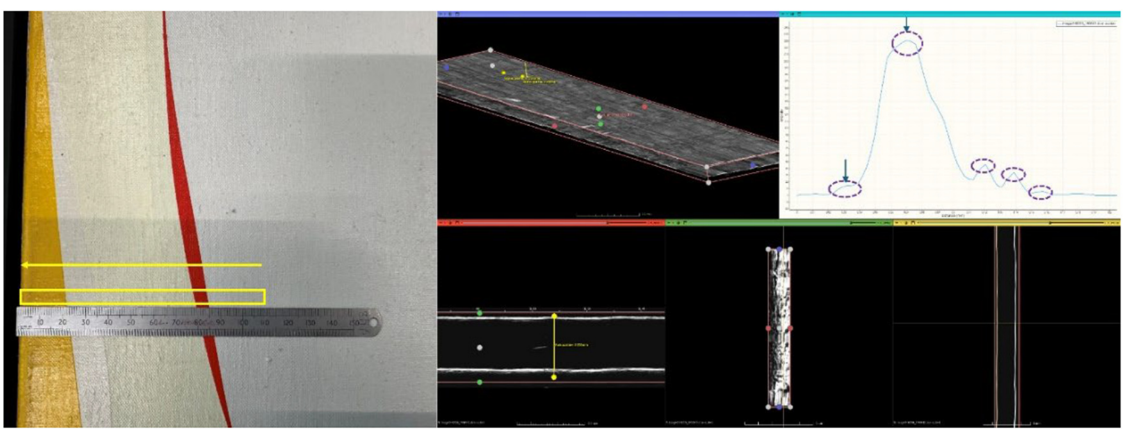


Fig. 7. Acoustic Tomography, ROI#1–4, Winter Sun. Left: scanning area 16mm x 110mm (16mm of scanning distance of ultrasonic transducer inside the probe and scanning length on the painting of 110mm) with the ultrasonic, dry-contact probe (area and direction marked in yellow). Right: overview of the ultrasonic measurements, namely the b-scans (axial and sagittal); the coronal (top view slice in a depth between varnish and paint layers); the c-scan (tomography); a line profile from the area marked with yellow line in which the various changes of the phase of the signal (layers, sublayers etc.) are depicted. The entire stratigraphy of the painting is revealed: five layers of varnish and paint can be observed and are marked with dashed purple circles.

the artist, or the red layer could have been a later compositional change.

While OCT revealed information about the transparent upper layers only, ultrasonic tomography showed the entire painting's stratigraphy. This technique enabled a more representative assessment, since the layer thickness could be characterised across the entire painting surface. The thickness of the varnish was calculated from the distance between the first two echoes in the scanned area (dimensions 16×110 mm, covering ROI#4 and ROI#2; Fig. 7). A total of five layers were resolved for *Winter Sun*, including varnish, paint, and ground, with varnish thickness measurement supporting the OCT results (4–40 µm). These findings thus provide an understanding of the painting process and layer build-up, without the need for taking physical cross-sections.

The varnish was identified with ERIRS in the mid-IR range as acrylic dispersion resin with the following characteristic bands (Fig. 8): C-H stretching at high wavenumber (ca. 3000 cm^{-1}); C=O stretching at ca. 1730 cm^{-1}; the C-H bending doublet at ca. 1465 cm^{-1} and 1380 cm^{-1} and at 854 cm^{-1} (rocking); the C-O-C, C-C and C-O stretching modes at 1240 cm^{-1} and ca. 1180 cm^{-1}. Comparison with reference spectra of Plextol P500, representative of a poly(ethyl acrylate/methyl methacrylate) co-polymer p(EA/MMA), shows a high match (visualised with the black line). However, some variability can be observed among the spectra, which can be attributed to different morphological characteristics, as well as the presence of additional features arising from the inorganic paint components, such as sulfates, carbonates and silicates, and the potential migration of the PEO/PEG surfactant to the surface. This effect is particularly evident in the spectra of ROI#7, ROI#9, and ROI#10 (Fig. 8), and is further confirmed by comparison with a Plextol P500 reference showing surfactant phase separation. The main IR signals of the migrated surfactant are highlighted by asterisks (red line) [32].

Notably, these results highlight the possibility of using non-invasive IR techniques to distinguish between different acrylic-based polymers and an in-depth ERIRS study of acrylic varnishes and binders of reference materials is currently ongoing.[14] Short wave infrared (SWIR) imaging and principal component analysis (PCA) applied to the spectra could assist with interpretation by grouping polymers according to chemical composition [33].

[14] Chemistry students at The Institute of Chemical Science and Technology-SCITEC of CNR, Italy, performed an in-depth IR study of acrylic varnishes and binders of reference materials and a publication is forthcoming.

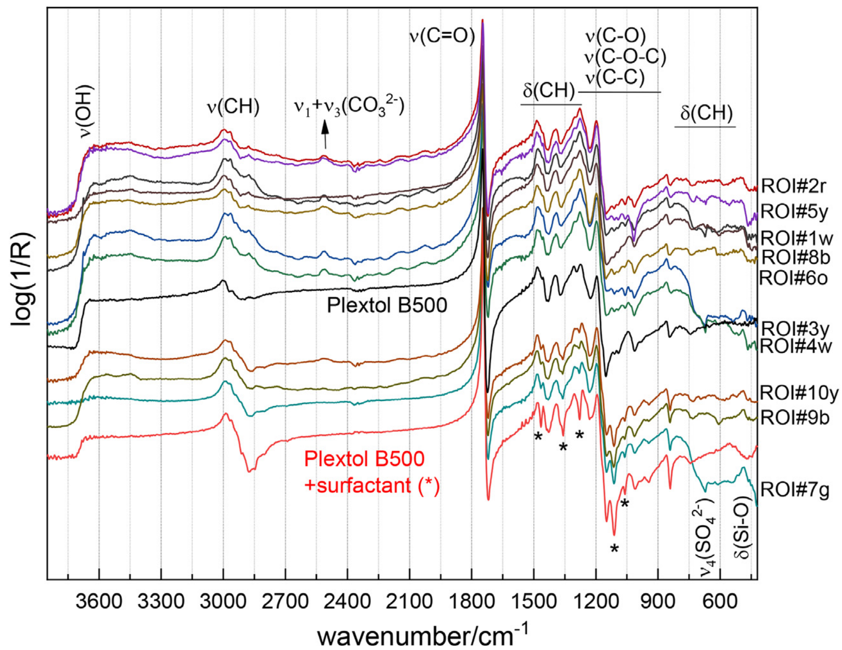


Fig. 8. ERIRS spectra in the mid-IR range recorded on multiple ROIs on Winter Sun. Spectra are compared with IR profiles from reference materials, Plextol P500 [p(EA/MMA), with and without the signals of the surfactant PEO/PEG, black and red lines respectively]. The main vibrational modes of both organic and inorganic paint components are indicated: *marks PEO/PEG signals; r=red; y=yellow; w=white; b=blue; o=orange; g=green.

The identification of EA/MMA corresponds with the date of the painting (1966), since EA/MMA was the first copolymer used in acrylic emulsion paint and coatings technology [34]. An empirical hardness test on the painting, carried out by gently applying a scalpel blade to the varnish surface, confirmed the soft, flexible nature typical of acrylic dispersions rather than harder solution-based varnishes. Further confirmation via transmission FTIR and Py-GCMS on microsamples is planned to resolve co- or terpolymer content and the presence of additives [35–40].

4.4. Summary of comparative findings across the case study group

The seven other paintings revealed both shared and divergent material choices, summarised in Table 3. The ground layers in the paintings dated before 1982 were PVAc-based, with formulations resembling household products such as Jotaplast. Vinyl-based paints also dominated the earlier works. Although only two works post 1980 were analysed, there is a possible trend to transition to acrylics by 1982. Only the two paintings by Tor Hoff featured PVAc resin varnishes, while the painting by Anders Kjær (1980) potentially has an acrylic-vinyl copolymer varnish layer. This requires further investigation and analysis of micro-samples from the painting using transmission FTIR and Py-GCMS to be certain. Kjær is known to use Liquitex acrylic medium as a varnish layer[15] and the results could therefore indicate that Liquitex medium from 1980 was an acrylic-vinyl copolymer. All other paintings exhibited acrylic dispersion resin varnishes, with those by Skedsmo and Arneberg showing evidence of EA/MMA copolymer compositions. This is somewhat unexpected given the date of the two paintings (1980 and 1982 respectively), since most artist varnish formulas had switched to using butyl acetate (BA) rather than EA by the 1980s [29,41]. Again, further investigation is required to be certain.

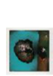
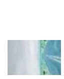
[15] Personal correspondence between Kjær and Homer, 15 February 2024, and *Informasjon fra kartotek "Materialbruk i moderne malerier i Nasjonalgalleriets eie"*.

4.5. Implications for conservation and varnish removal strategies

The findings of this study directly inform current concerns in conservation surrounding the removal of synthetic varnishes from waterborne paint films. The identification of waterborne acrylic dispersion varnishes on most of the case study paintings challenges long-held assumptions that solvent-based acrylic solutions were the primary coating type. Dispersion varnishes are marketed as permanent or "non-removable" by the manufactures, intended for use as an isolation layer prior to a final varnish [4]. They are usually based on the acrylic medium used in the paints and are therefore particularly problematic due to their comparable solubility and mechanical properties relative to the underlying paint. This chemical and physical similarity significantly raises the risk of swelling, undercutting, or removal of original material during cleaning. Conventional varnish removal techniques are thereby rendered ineffective or unsafe. However, the hypothesis that precise solvent selection and refined gel application can reliably target only the varnish is equally problematic. As shown through techniques such as OCT and ultrasonic tomography, these modern varnishes are often extremely thin, and the layer structure is often more complicated than expected. Irregular surface texture, presence of specific pigments, and potential interaction between layers complicates selective removal even further.

This study highlights the urgent need for conservation strategies that consider not only chemical interactions and solubility of varnish and paint layers, but also the material history and artistic intent. By mapping the detailed chemical composition and stratigraphy of the paint and varnish systems, this research paves the way for more nuanced approaches to acrylic varnish removal and provides a critical foundation for designing realistic mock-ups that reflect actual materials used by Norwegian artists during this period. Such mock-ups would facilitate systematic testing of cleaning methods, enabling controlled evaluation of risk and efficacy. In this way, the research not only clarifies what materials are present but also informs how conservators might proceed with greater confidence, contextual understanding, and ethical sensitivity.

Table 3
Overview of media and pigment analysis by ERIRS and XRF mapping of the eight case study paintings; varnish stratigraphy information gathered with OCT and ultrasonic tomography. Question marks indicate uncertainty of the results.

Image	Artist	Title	Date	Registered media in database	Ground layer binder	Paint binder	Extenders/pigments (ERIRS, XRF map)	Varnish binder	Varnish layers & thickness
	Gunnar S. Gundersen	Winter Sun	1966	Acrylic	PVAc resin	PVAc resin	Titanium white; calcite; likely talc. Possibly cadmium yellow, synthetic organic red, cobalt blue, phthalocyanine blue	Acrylic dispersion resin (possibly EA/MMA)	Single layer; 4-45μm thick
	Per Kleiva	Beams from the Ashes	1972	Acrylic	PVAc resin	Acrylic resin	Titanium white (rutile); calcite; dolomite.	Acrylic dispersion resin (possibly BA/MMA)	Sometimes two layers; 1-38μm thick
	Tor Hoff	The Golden Break	1974	Acrylic	PVAc resin	PVAc resin	Titanium white; dolomite; likely kaolinite. Possibly bone black; earth pigments; gold spray paint (copper & zinc)[16]	PVAc resin	Single layer; 3-45μm thick
	Tor Hoff	Great Heavenly Stone	1975	Acrylic	PVAc resin	PVAc resin	Titanium white (possibly anatase); dolomite; kaolinite.	PVAc resin	Single layer; 2-26μm thick
	Anders Kjær	Before the Storm	1980	Acrylic	PVAc resin	PVAc resin?	Titanium white (possibly rutile); calcite; kaolinite. Possibly ivory black, iron oxide pigments	Acrylic dispersion resin (possibly vinyl-acrylic copolymer)	Could not be resolved in most places
	Dag Skedsmo	Untitled	1980	Acrylic	PVAc resin	PVAc resin	Titanium white; kaolinite; calcite; dolomite. Possibly phthalocyanine blue.	Acrylic dispersion resin (possibly EA/MMA)	Single layer; 5-27μm thick
	Anna Eva Bergman	Double Mountain	1982	Acrylic	Acrylic resin	Acrylic resin?	Titanium white; possibly ultramarine blue.	Ketone resin	Single layer; 3-20μm thick
	Marianne Arneberg	Fruit I	1982	Acrylic	Acrylic resin	Acrylic resin	Titanium white; calcite.	Acrylic dispersion resin (possibly EA/MMA)	Single layer; 4-30μm thick

[16] The gold paint consists of copper and zinc, which are found in combination in contemporary industrial metallic spray paints: https://doi.org/10.1016/j.jas.2005.10.006 [accessed 27.11.24].

5. Conclusions

This study presents, for the first time, the non-invasive analytical results of a group of Norwegian Modernist paintings executed in and varnished with waterborne acrylic dispersion or PVAc media. The results demonstrate the effectiveness of a multimodal, non-invasive analytical approach to characterise these complex material systems. Through the in-depth analysis of *Winter Sun*, which integrated OCT, ERIRS, XRF mapping, optical microprofilometry, ultrasonic tomography, and digital microscopy, it was possible to: (i) identify the varnish layer's composition, distribution, thickness and degradation; (ii) identify paint binders and pigments; (iii) reconstruct layer stratigraphy; (iv) reveal the paint and varnish morphology and surface characteristics.

By extending the multimodal approach to the seven additional case study paintings, this research also identified shared features and significant material differences across the group, and the mixed methodology enabled the mapping of materials and methods used by select artists in Norway during the 1960s–1980s. These comparative findings revealed the range of industrial and artist-grade materials that artists embraced in Norway during this period, particularly vinyl-based primers and paints up until the 1980s, and waterborne acrylic dispersion varnishes. As a result of the study, corrections were made to the museum's database records, in terms of material composition, which allowed contextualisation within the Norwegian paint market at the time, thereby enhancing both conservation decision making and art-historical understanding.

While this study benefitted from access to multiple analytical techniques through MOLAB, the amount of data gathered was immense and there was significant overlap of information, especially with OCT and tomography. Furthermore, much of the information gathered was also revealed through simpler methods such as visual observation in raking light and digital microscopy. For example, air bubbles within the paint layers were easily resolved with both micro-profilometry and OCT, but these were also visible with optical microscopy. The layering of different paint passages was evident with micro-profilometry but was also easily understood through examination with raking light and digital microscopy. Nevertheless, visual recognition of acrylic and vinyl paints can be challenging, and precise identification of the polymers and binders present is not possible without IR spectroscopy methods, such as ERIRS. Likewise, the value of OCT for painting conservators has been demonstrated in this and other publications [18,42–48], and it is hoped that this analytical tool will be more easily accessible to conservators and researchers in the future.

Acknowledgements

The first author would like to acknowledge the continual support and guidance of her PhD supervisors, Professor Noëlle Streeton, Professor Gunnar Heydenreich and Dr. Bronwyn Ormsby. Thanks also go to the Head of Conservation at the National Museum of Norway, Kari Skytt Andersen for enabling this research project.

Author Contributions

The methodology of this project was devised by LH following the successful application to MOLAB in spring 2022. Initial visual observations, examination and assessment of the paintings were carried out by LH, along with micro-XRF analysis and 3D digital microscopy. Digital photography was carried out by Børre Høstland in the photography department at the National Museum. OCT at 850 nm was carried out and interpreted by PT, MK, and MI, while

OCT at 1350 nm was carried out by CSC and HL, with interpretation by PA and FL. In-situ ERIRS was carried out by DB and LC, with interpretation carried out by FR. Micro-profilometry was carried out by RF; profile extraction and modelling were done by EV and IL. Ultrasonic tomography was carried out and interpreted by GK and TK. BO and AB contributed to analytical interpretation and guided plans for invasive analysis. LH was responsible for the drafting of the original manuscript. All authors edited multiple versions of the manuscript and approved the final one for submission.

Funding

The mobile, non-invasive analytical research was supported by IPERION HS – Integrating Platforms for the European Research Infrastructure ON Heritage Science Project Horizon 2020 Programme of the EU (Grant Agreement n.871034). The contents reflect only the authors' view, and the European Commission is not responsible for any use that may be made of the information it contains.

The PhD research project is funded by The National Museum of Norway.

References

[1] M.-C. Cyr, E. Min, and A. Murray, 'Extended abstract—the removal of commercial varnishes from acrylic paints', p. 6, 2012.
[2] B. Ormsby, P. Smithen, M. Cross, E. Kampasakali, L.C. Aasen, An evaluation of artists' and conservation varnishes for acrylic emulsion paint films, in: Proceedings of ICOM Committee for Conservation 16th Triennial Meeting Lisbon Portugal 19-23 September 2011, Lisbon, Critério Artes Gráficas, 2011 Lda.; ICOM Committee for Conservation.
[3] P. Smithen, A history of the treatment of acrylic painting, in: T. Learner, P. Smithen, J. Krueger, M. Schilling (Eds.), Modern paints uncovered : proceedings from the modern paints uncovered symposium, Getty Conservation Institute, Eds, Los Angeles, 2007, pp. 165–174.
[4] M. Golden, Ch. 12- varnishing of acrylic paintings by artists.pdf, in: J.Hill Stoner, R. Rushfield (Eds.), The Conservation of Easel Paintings, 2nd edn, Routledge, 2022, p. 948.
[5] Anonymous, Acrylic paints for the fine arts, Resin Rev. 16 (3) (1966) 12–16.
[6] E.A. Willneff, S.L. Schroeder, B.A. Ormsby, Spectroscopic techniques and the conservation of artists' acrylic emulsion paints, Herit. Sci. 2 (1) (Dec. 2014) 25, doi:10.1186/s40494-014-0025-y.
[7] E. Jablonski, T. Learner, J. Hayes, M. Golden, Conservation concerns for acrylic emulsion paints, Stud. Conserv. 48 (sup1) (June 2003) 3–12, doi:10.1179/sic.2003.48.Supplement-1.3.
[8] B. Ormsby, 'An FTIR-based exploration of the effects of wet cleaning treatments on artists' Acrylic emulsion paint films', 2009.
[9] B. Ormsby, 'Revisiting cleaned acrylic emulsion painting surfaces ten years on: observations and reflections', 2021.
[10] B. Ormsby, T. Learner, Artists' acrylic emulsion paints: materials, meaning and conservation treatment options, AICCM Bull. 34 (1) (Dec. 2013) 57–65, doi:10.1179/bac.2013.34.1.007.
[11] B. Ormsby, et al., Mineral spirits-based microemulsions: A novel cleaning system for painted surfaces, J. Am. Inst. Conserv. 55 (1) (Jan. 2016) 12–31, doi:10.1080/01971360.2015.1120406.
[12] B. Ormsby, A. Bartoletti, K.J. Van Den Berg, C. Stavroudis, Cleaning and conservation: recent successes and challenges, Herit. Sci. 12 (1) (Jan. 2024) 10 s40494-023-01113–0, doi:10.1186/s40494-023-01113-0.
[13] A. Bartoletti, et al., Reviving WHAAM! a comparative evaluation of cleaning systems for the conservation treatment of Roy Lichtenstein's iconic painting, Herit. Sci. 8 (1) (Dec. 2020) 9, doi:10.1186/s40494-020-0350-2.
[14] J. Fredly, Konkret kunst i Norge i 50-årene: en undersøkelse av malerier og utsmykninger av Odd Tandberg, Gunnar S. Gundersen, Jakob Weidemann, Ludvig Eikaas og Gudrun Kongelf', Hovedfagsoppgave kunsthistorie (2005).
[15] J. Askeland, Dialog om abstrakt kunst. Apropos en utstilling i Kunstnerforbundet, Verdens Gang (Feb. 25, 1950).
[16] F. Rosi, A. Daveri, P. Moretti, B.G. Brunetti, C. Miliani, Interpretation of mid and near-infrared reflection properties of synthetic polymer paints for the non-invasive assessment of binding media in twentieth-century pictorial artworks, Microchem. J. 124 (Jan. 2016) 898–908, doi:10.1016/j.microc.2015.08.019.
[17] I. Bargagli, et al., Assessing mechanochemical properties of acrylonitrile butadiene styrene (ABS) items in cultural heritage through a multimodal spectroscopic approach, Appl Spectrosc 78 (12) (Dec. 2024) 1316–1328, doi:10.1177/00037028241267325.
[18] P. Targowski, M. Iwanicka, B.J. Rouba, C. Frosinini, OCT for examination of artwork, in: Optical Coherence Tomography: Technology and Applications, Springer International Publishing, Cham, 2015, pp. 2473–2495.
[19] M. Iwanicka, et al., Congregation leaving the Reformed Church in Nuenen by Vincent van Gogh: a combined multi-instrumental approach to analyse the painting's stratigraphy in support of varnish removal, Herit Sci 10 (1) (Oct. 2022) 167, doi:10.1186/s40494-022-00789-0.
[20] H. Liang, B. Peric, M. Hughes, A.G. Podoleanu, M. Spring, S. Roehrs, Optical coherence Tomography in archaeological and conservation science - a new emerging field', presented at the 1st Canterbury Workshop and School in Optical Coherence Tomography and Adaptive Optics, Sept. 2008, doi:10.1117/12.819499.
[21] P. Targowski, M. Kowalska, M. Sylwestrzak, M. Iwanicka, OCT for examination of cultural heritage objects', in: M.R. Wang (Ed.), Optical Coherence Tomography and Its Non-medical Applications, IntechOpen, 2020, doi:10.5772/intechopen.88215.
[22] G. Karagiannis, D. Alexiadis, G. Sergiadis, C. Salpistis, Processing of UV/VIS/nR/miR diffuse reflectance spectra and acoustic microscopy echo graphs for stratigraphy determination, using neural networks and wavelet transform, 2008 3rd International Conference on Information and Communication Technologies: From Theory to Applications, 2008, IEEE, 2008, doi:10.1109/ICTTA.2008.4529904.
[23] G. Karagiannis, D.S. Alexiadis, A. Damtsios, G.D. Sergiadis, C. Salpistis, Three-dimensional nondestructive "sampling" of art objects using acoustic microscopy and time–Frequency analysis, IEEE Trans. Instrum. Meas. 60 (9) (Sept. 2011) 3082–3109, doi:10.1109/TIM.2011.2124730.
[24] G. Marchioro, G. Apostolidis, G. Karagiannis, M. Galeotti, C. Daffara, Surface and subsurface layers characterization in artworks using conoscopic laser holography and acoustic microscopy, in: Proceedings of SPIE - The International Society for Optical Engineering, 10331, SPIE, 2017 *103310L-8Article* 103310L2017, doi:10.1117/12.2270321.
[25] G. Karagiannis, S. Amanatiadis, E. Mimis, Accurate motion plan of ultrasonic linear array transducer for non-destructive 3D endoscopy of iconic cultural heritage assets, in: 2019 IEEE International Conference on Imaging Systems and Techniques (IST), Abu Dhabi, United Arab Emirates, IEEE, Dec. 2019, pp. 1–5, doi:10.1109/IST48021.2019.9010447.
[26] G. Karagiannis, T. Karagiannis, E. Karagiannis, Multiscale and multiresolution analysis of cultural heritage objects using ultrasonics from 32KHz to 50MHz. The case of Pantokratoros Monastery in Mount Athos, in: 2023 IEEE International Ultrasonics Symposium (IUS), Montreal, QC, Canada, IEEE, Sept. 2023, pp. 1–3, doi:10.1109/IUS51837.2023.10306495.
[27] B. Hartmann, J. Jarzynski, Immersion apparatus for ultrasonic measurements in polymers, J. Acoust. Soc. Am. 56 (5) (Nov. 1974) 1469–1477, doi:10.1121/1.1903466.
[28] M. Sinha, D.J. Buckley, Acoustic properties of polymers, in: J.E. Mark (Ed.), Physical Properties of Polymers Handbook, Springer, New York, NY, 2007, pp. 1021–1031.
[29] T. Learner, Analysis of Modern Paints, Getty Conservation Institute, Los Angeles, 2004.
[30] C. Defeyt, J. Van Pevenage, L. Moens, D. Strivay, P. Vandenabeele, Micro-raman spectroscopy and chemometrical analysis for the distinction of copper phthalocyanine polymorphs in paint layers, Spectrochim. Acta A: Mol. Biomol. Spectrosc. 115 (Nov. 2013) 636–640, doi:10.1016/j.saa.2013.04.128.
[31] C. Defeyt, 'PB15 as 20th and 21st artists' Pigments: conservation concerns', 2014.
[32] M.Melchiorre Di Crescenzo, E. Zendri, C. Miliani, F. Rosi, A preliminary FTIR-based exploration of the surfactant phase-separation process in contemporary mural paintings, e-PRESERV. Sci. 10 (Jan. 2013) 10–18.
[33] J.D. Cutajar, A. Babini, H. Deborah, J.Y. Hardeberg, E. Joseph, T. Frøysaker, Hyperspectral imaging analyses of cleaning tests on Edvard Munch's monumental aula paintings, Stud. Conserv. 67 (sup1) (Aug. 2022) 59–68, doi:10.1080/00393630.2022.2054617.
[34] T. Learner, Modern Paints, in: *Scientific Examination of Art: Modern Techniques in Conservation and Analysis*, National Academy of Sciences, The National Academies Press, Ed., Washington, DC, 2005, p. 254, doi:10.17226/11413.
[35] T.J.S. Learner, The characterisation of acrylic painting materials and implications for their use, conservation and stability, PhD Chem. (1997).
[36] A. Mejía-González, S. Zetina, M.E. Espinosa-Pesqueira, N. Esturau-Escofet, Characterization of commercial artists' acrylic paints and the influence of UV light on aging, Int. J. Polym. Anal. Charact. 22 (6) (Aug. 2017) 473–482, doi:10.1080/1023666X.2017.1324753.
[37] D. Scalarone and O. Chiantore, 'Ageing studies of acrylic emulsion paints. Part II. Comparing formulations with poly(EA-co-MMA) and poly(n-BA-co-MMA) binders', 2005.
[38] O. Chiantore, D. Scalarone, T. Learner, Characterization of artists' Acrylic emulsion paints, Int. J. Polym. Anal. Charact. 8 (1) (Jan. 2003) 67–82, doi:10.1080/10236660304884.
[39] P. Schossler, I. Fortes, J.C.D.D.F. Júnior, F. Carazza, L.A.C. Souza, Acrylic and vinyl resins identification by pyrolysis-gas chromatography/mass spectrometry: A study of cases in modern art conservation, Anal. Lett. 46 (12) (Aug. 2013) 1869–1884, doi:10.1080/00032719.2013.777925.
[40] T. Fardi, V. Pintus, E. Kampasakali, E. Pavlidou, M. Schreiner, G. Kyriacou, Analytical characterization of artist's paint systems based on emulsion polymers and synthetic organic pigments, J. Anal. Appl. Pyrolysis 135 (Oct. 2018) 231–241, doi:10.1016/j.jaap.2018.09.001.
[41] J. Crook, T. Learner, The Impact of Modern Paints, Tate Gallery Publishing Ltd, London, 2000.
[42] M. Iwanicka, et al., Complementary use of Optical Coherence Tomography (OCT) and reflection FTIR spectroscopy for in-situ non-invasive monitoring of varnish removal from easel paintings, Microchem. J. 138 (May 2018) 7–18, doi:10.1016/j.microc.2017.12.016.
[43] T. Ford, M. Iwanicka, E. Platania, P. Targowski, E. Hendriks, Munch and optical coherence tomography: unravelling historical and artist applied varnish layers

in painting collections, Eur. Phys. J. Plus 136 (9) (Sept. 2021) 899, doi:10.1140/epjp/s13360-021-01758-5.
[44] R. Fontana, et al., Application of non-invasive optical monitoring methodologies to follow and record painting cleaning processes, Appl. Phys. A 121 (3) (Nov. 2015) 957–966, doi:10.1007/s00339-015-9505-5.
[45] J. Yao, J.P. Rolland, Optical coherence tomography for polymer film evaluation, in: M.R. Wang (Ed.), Optical Coherence Tomography and Its Non-medical Applications, IntechOpen, 2020, doi:10.5772/intechopen.90445.
[46] P. Targowski, M. Iwanicka, L. Tymińska-Widmer, M. Sylwestrzak, E.A. Kwiatkowska, Structural examination of easel paintings with optical coherence tomography, Acc. Chem. Res. 43 (6) (June 2010) 826–836, doi:10.1021/ar900195d.
[47] J. Striova, et al., Modern acrylic paints probed by optical coherence tomography and infrared reflectography, Microchem. J. 138 (May 2018) 65–71, doi:10.1016/j.microc.2017.12.027.
[48] I. Gorczyńska, et al., Varnish thickness determination by spectral optical coherence tomography, in: Lasers in the Conservation of Artworks, Springer Berlin Heidelberg, Berlin, Heidelberg, 2007, pp. 493–497, doi:10.1007/978-3-540-72130-7_58. Springer proceedings in physics.