# DELAMINATION OF THE PAINT STRUCTURE IN *PEINTURE*, DATED 1954 BY PIERRE SOULAGES

## A STUDY ON SOAP FORMATION IN THE PAINT LAYER INTERFACE


## Abstract

*Peinture*, 1954, by Pierre Soulages exhibits substantial delamination of the upper paint layers. Micro samples were collected from the different layers of the paint structure to provide further insights into the layer chemistry. The analysis revealed FTIR peaks indicative for high levels of zinc soaps at the interfaces on each side of a light-yellow zinc containing paint layer. Delamination is only occurring in areas beneath black paint features, suggesting that the black paint is playing a role. Analysis of the upper black paint revealed features characteristic for mobile oxidised free and acylglycerol bound fatty acids and diacids similar to those found in earlier studies of paintings with soft and dripping paint. The mobile fraction of the black paint is thought to be the source of fatty acids leading to zinc soap formation in the layer beneath. Samples were analysed with various microscopic and spectroscopic techniques. The results support the hypothesis that mobile fractions exuding into the layer structure enable the development of new compounds that weaken the adhesion of the layers by expansion and alteration of its physical properties, thus explaining the mechanisms resulting in the delamination. This investigation of the artwork emphasizes the importance of future preventive conservation strategies.



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## Introduction

To best preserve the art of Pierre Soulages (1919-) for the future there are two topics that conservation professionals will have to address: his soft black oil paint and the severe delamination of some of his paintings. A study was performed to investigate the possible relationship between these two symptoms, by examination and chemical analysis of microsamples from *Peinture*, 1954, in the Henie Onstad Art centre collection in Norway.

### Peinture

The French artist Pierre Soulages has, throughout his career, investigated the juxtaposition of light and dark. He has used black to evoke both the presence of snow in early landscapes and light for the viewer of his artworks. In his later paintings, the reflection of light achieved a lively representation of the painted surface. In his earlier works, the texture of the black paint strokes is an important part of the experience (Figure 1). Delamination of the paint layers however, directly affects the visual effect of the surface.

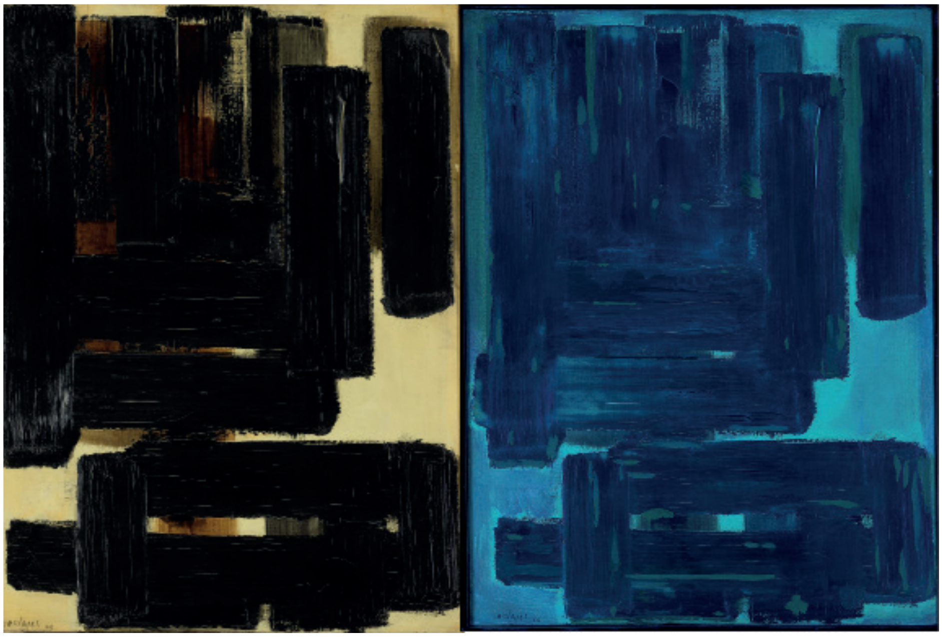

Figure 1. Pierre Soulages, *Peinture*. Oil on canvas, 81 x 60 cm. Henie Onstad Art Centre. In normal light (left) and luminescence from UV light (right). Photos: National Museum, Børre Høstland.

Figure 2. Detail from *Peinture*, in normal light (left) and showing the luminescence from UV light (right). Photos: National Museum, Børre Høstland.

*Il y a de la lumière réfléchie par le noir, donc déjà modifiée, transformée. Si elle était réfléchie par du vert, du bleu ou par un miroir, ce ne serait pas la même. On voit de la lumière qui provient du tableau vers celui qui regarde : ça, c'est ce qui se passe dans ma peinture, c'est le côté optique […]. Si la lumière change de place, ce n'est plus la même peinture que l'on voit; et si le regardeur bouge, ce n'est pas tout à fait la même chose qu'il voit.*

Pierre Soulages (Charliat 2019).

*The light is reflected by the black, therefore it is already modified, transformed. If it was reflected by green, blue, or a mirror, it would not be the same. We see the light coming from the painting towards the viewer: that is what happens in my painting, it is the optical aspect [...]. If the light changes position, it is no longer the same painting that we see; and if the viewer moves, it's not quite the same thing they see.*
(Translated to English by the first author).

The paint texture, the precision of the strokes and the shade or colour of the paint is fundamental to Soulages's artistic intent. Hence, when delamination of part of the structure interrupts our view, it changes our experience. The viewer can to some extent understand a change in the materials and look past it, particularly if they already know something about the work's age and the artist. Still there is a tipping point when the damage starts to change the visual impact excessively. In the worst cases, damage to the paint structure will dominate and stand in the way of the work being displayed in exhibitions. *Peinture* by Pierre Soulages shows this type of severe delamination.[1] Similar damage has been observed in other paintings by Soulages in both Norwegian and Finnish collections (Helou-de la Grandière et al. 2021). Soulages's paintings are not uniquely affected by this type of delamination; the same damage has been observed in works by other modern painters, for example Asger Jorn (1914-1973), Paul-Émile Borduas (1905-1960), Karel Appel (1921-2006), Hans Hofmann (1880-1966) and Georges Mathieu (1921-2012) among others (Challan-Belval 1991; Rogala et al. 2010; Ségogne, H. de 2012; Ségogne, H. de 2014; Bronken et al. 2019; O'Malley 2019). The findings from the various examinations of Peinture should therefore be a relevant supplement to earlier findings.

## Soulages's material history

The material history of an artist is one of the sources in discussions of potential cause and effect of condition issues. The practical context for an artist's practice and work is an important part of understanding the artworks and their condition. Much information is already known about Soulages's materials (La Grandiere, de 2005; Hélou-de La Grandière et al. 2008 ; Hélou-de La Grandière 2019). It is well-known that the two companies Lucien Lefebvre-Foinet and Adam Montparnasse in Paris were Soulages's main suppliers (Hélou-de La Grandière et al. 2008; Corbeil et al. 2011). Observation of the technique used for *Peinture* identified several different glazes and transparent layers over and under the black paint strokes (Figure 1 and 2). This correlates with observations made on other paintings by Soulages at the time.

Since the painting studied here was painted in 1954, it was of interest to search for additional data about Pierre Soulages's technique at that time. One of the photographers who documented many of the artists congregating on the Left Bank in Paris in the 1950s was Denise Colomb. Her photographs are now in the Réunion des Musées Nationaux photographic archive (RMN in Paris). Colomb took a series of photographs of Pierre Soulages in his studio at 11 Rue Victor Schoelcher (Ragon 2004) in 1954 (Figure 3).

No logos or clear details are obvious in the photographs taken by Colomb. Still, two of the bottles have enough details to compare the information to known paint brand logos of the time. One glass bottle has an embossed logo on made in the glass that looks very similar to the logo of Lefranc Cie (1720-1965) seen in the mid-1900s (Figure 3, detail). The oval logo on the bottle to the far right, although not in full view or focus, is interpreted as the Talens logo (Figure 3, detail).

We know that Adam Montparnasse sold materials from Lefranc in addition to his own mixtures and blends (Andrieu et al. 2011). Soulages visited the shop regularly from 1946 (Andrieu et al. 2011). Talens' products might have been retailed by several shops in the Montparnasse area. As Soulages worked consistently in Paris at this time it is likely that the Talens brand was available in the local shops although it has not been possible to confirm this from other sources.

Figure 3. Pierre Soulages in his studio, 1954. Photo: Denise Colomb: Réunion des Musées Nationaux Agence Photographique (RMN). Underneath: Detail from figure 3 with interpreted historic logos. Illustration: Ida Bronken.

The worktable of Soulages shows both paint tins and tubes. Their logos are not visible, but the tube on the far right has raised lettering on the upper surface against the neck. The French paint brands mentioned in connection with Soulages - Lefranc, Bourgeois and Lefebvre-Foinet - have all raised lettering around the opening of historic tubes, so these brands are all candidates for matches with the tube on the right. Both the brand of Lefranc and Lefebvre-Foinet are mentioned in connection to other studies on soft paint, however, more work is needed on the material paint history of the 1950s and 1960s before the information from individual artists can be discussed with more certainty in connection with condition issues. The available documentation about Peinture supports the impression that Soulages made several additions to his paint at the time.

## Painting technique and layer build-up

*Peinture* is among the early works of Soulages, and is painted with a juxtaposition of opaque, translucent and transparent layers (Figure 2). Unlike what we see in later works, the paint is not particularly pastose , and the surface is either unevenly varnished or given finishing touches of the coloured and transparent paint/glazes observed elsewhere in the painting structure (Figure 1 and 2). The support is canvas with a commercially applied ground. Judging from a cross-section, the ground is a two-layer application (Figure 8). The pre-primed canvas is most likely from the firm Lucien Lefebvre-Foinet, based on the shape and faint lettering of a stamp found on the reverse. Superimposed over the ground layer is a light-yellow paint, which functions as a background colour, covering the ground completely (Figure 1 and 8). From the luminescence seen from exposure to UV light, we can see more clearly that the background colour in normal light is painted over with a slightly deeper shade of yellow in areas towards the edges. The deeper shade of yellow has less luminescence in UV light and can be seen as darker areas (Figure 1 and 2). From purely visual observation, it is suspected that the background colour is leaner than both the ground and the black paint layer due to its matte appearance. The main motif has been built up with large black paint strokes, with tool marks corresponding to a broad and flat brush. The brush strokes are long, straight and defined – creating a subtle structural effect (Figure 4). Black and brown transparent glazes have been used by Soulages both over the background colour and above the black paint. Some of these transparent layers, coloured and luminescing orange in UV, were applied over drying cracks in the black paint (Figure 1 and 2). Under UV light there is a fluorescing or luminescing layer indicative of an uneven varnish (with or without pigmentation), but this has not been confirmed by analysis.

## Condition

The coloured glazes over the cracks in the black paint have been added after the development of the cracks, possibly by Soulages himself. After the initial drying cracks in the black paint, new issues developed resulting in the present condition. Several straight and linear cracks penetrate the upper paint layers. In the severe cases, these layers curl up, mainly creating a separation between the yellow background paint and the upper ground layer (Figure 4 and 6). Because the ground is most likely from the painting materials supplier Lucien Lefebvre-Foinet, it was likely that it was a lead white ground (La Grandiere, de 2005), which was later confirmed by analysis. This led to our working hypothesis that the delamination was a result of lead soaps from or on the upper layer of the ground (Helou-de la Grandiere 2008). From visual examination this is indeed where the adhesion is lost, but only in areas where the soft black paint is present (Figure 4). Hence, the idea that the soft black paint somehow contributed to the delamination issues in *Peinture.*

Figure 4. Detail of point of delamination in normal light. Photo: National Museum, Børre Høstland.

Delamination initiated by zinc soaps have been recently reported in a study on an Asger Jorn (1914-1973) painting in the same Norwegian collection (Bronken et al. 2019). Observations from a group of 20 paintings with soft and dripping paint from five Norwegian collections have shown that severe delamination occurs in combination with soft paint layers (Bronken, PhD thesis forthcoming). These delaminations have been observed in combination with zinc as well as lead containing layers. In paintings with soft paint over a lead white ground with delaminating paint layers, a glossy, transparent, web structure was observed (with the help of magnification) on the priming ground of the affected area. A similar phenomenon was also observed on *Peinture* (Figure 5).

Visible light and UV luminescence micrographs of the surface of the ground in a delaminated area are shown in Figure 5. The surface shows transparent, web-like elongated structures that have a blue luminescence under UV light (365 nm). These residual features suggest that when the ground and yellow background paint layers detached, a transparent residue was left on both sides of the delaminating layers. In some areas, the light yellow layer remains attached to the ground and the interface between the yellow and the black paint has detached. Figure 6 is a diagram illustrating the various layers in the delamination area. The illustration is based on both visual observation of the painting, and microscopic examination of cross sections made from embedded microsamples. The web-like structure on the interface with the ground is not the only sign of structural changes. On the interface between the yellow and the black paint layer a structural change is observable, with a more pronounced corrugated and ribbed texture. The Scanning Electron Microscopy (SEM) image at the top left corner of Figure 6 from the light yellow and black paint interface shows a corrugated structure with ridges and hollowed areas as if the delaminated area was rather soft and perhaps even fluid (Figure 6). Chemical investigation using Scanning Electron Microscopy Energy Dispersive X-ray spectroscopy (SEM-EDX) and Fourier Transform Infrared spectroscopy (FTIR) were used to identify the chemical compounds at the interface and their relationship to both over- and under-lying paint layers. For instrumental details see section *Experimental.* A previous study by Boon and Lister (2014) of another Pierre Soulages painting from 1960 reported that the binding media in the black paint and the exudates were rich in acidic oil derived fractions composed of free and glycerol-bound fatty acids and diacids. If similar mobile organic material was penetrating the lower layers of the *Peinture* it could provide a fatty acid source for a metal soap formation that would weaken the adhesion between the layers, leading to delamination. It was, therefore, important for comparative reasons, to take samples for FTIR, gas chromatography-mass spectrometry (GC-MS) and SEM-EDX to determine whether this was the case.

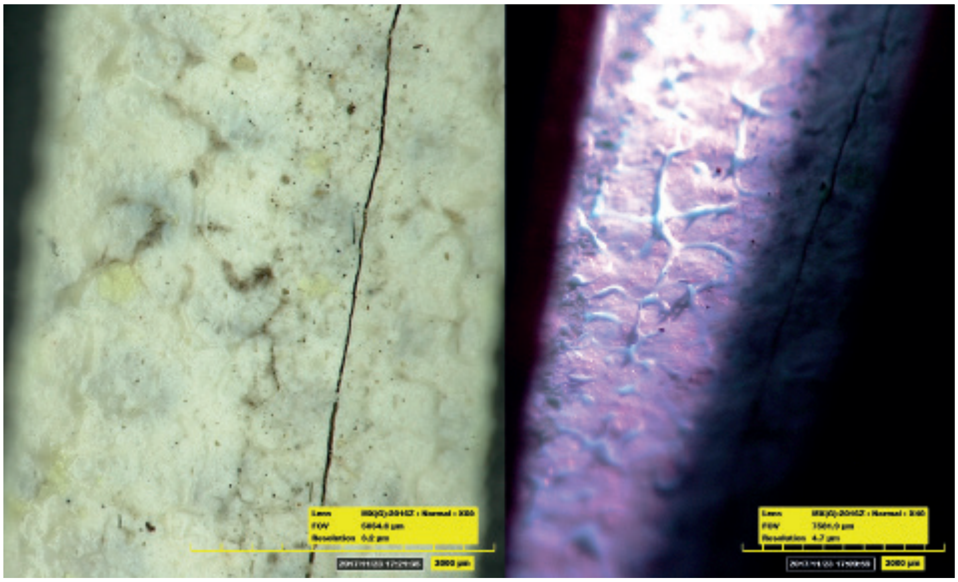

Figure 5. Area of delamination documented with Hirox microscope in normal light and the luminescence from hand-held raking UV light. A web of blue UV-luminescence residual elongated structures was visible on the delaminated interface. Photos: Jaap Boon.

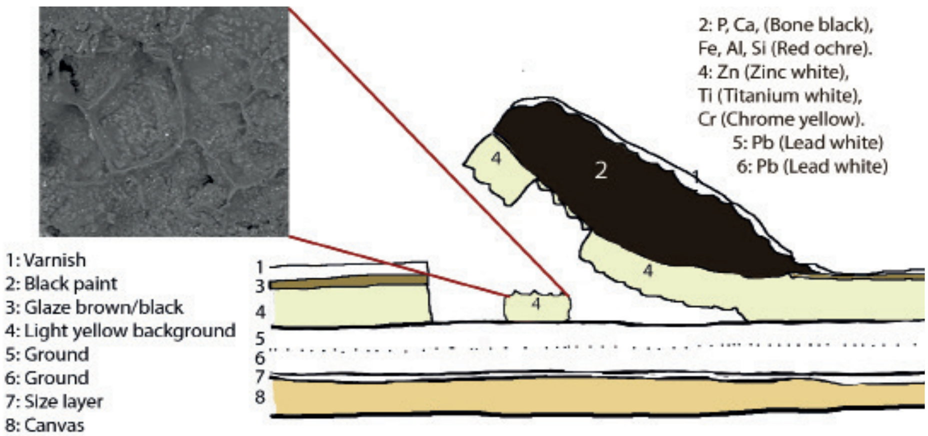


Figure 6. Illustration of the main layer structure. The layer thickness in the illustration is indicative. Both layer 1 and 3 vary greatly locally in both thickness and pigmentation. Illustration: Ida Bronken. The insert represents a SEM image of the delamination surface. SEM-EDX image: Calin Constantin Steindal.

## Layer structure and SEM-EDX analysis

The painting's structure has three main elements: two applications of a white ground layer (layer 5 and 6), a light yellow background colour (layer 4), and black paint that makes up the main motif (layer 2) illustrated in Figure 6, 7, 8 and 9. Figure 6 is a schematic illustration showing the overall layer structure of the painting. Figure 7 shows a cross-section of the upper layers in a delaminating area, while Figures 8 and 9 show a cross-section from the edge of a main motif which does not exhibit delamination. Based on the chemical elements identified with SEM-EDX, the white ground layers are composed of lead white. The yellow background paint contains titanium, chromium, some lead and zinc, suggesting a mixture of zinc white, titanium white and chrome yellow. The presence of calcium and phosphorous in the black paint indicates bone black. The black paint also contains red ochre; red particles containing iron, silicon and aluminium were identified by SEM-EDX. The SEM-EDX results confirmed the visual observations, that both the background paint and the black paint are specially made mixtures with more than one pigment. The addition of yellow and red pigments indicates that Soulages made these paint mixes to obtain a warmer tone.

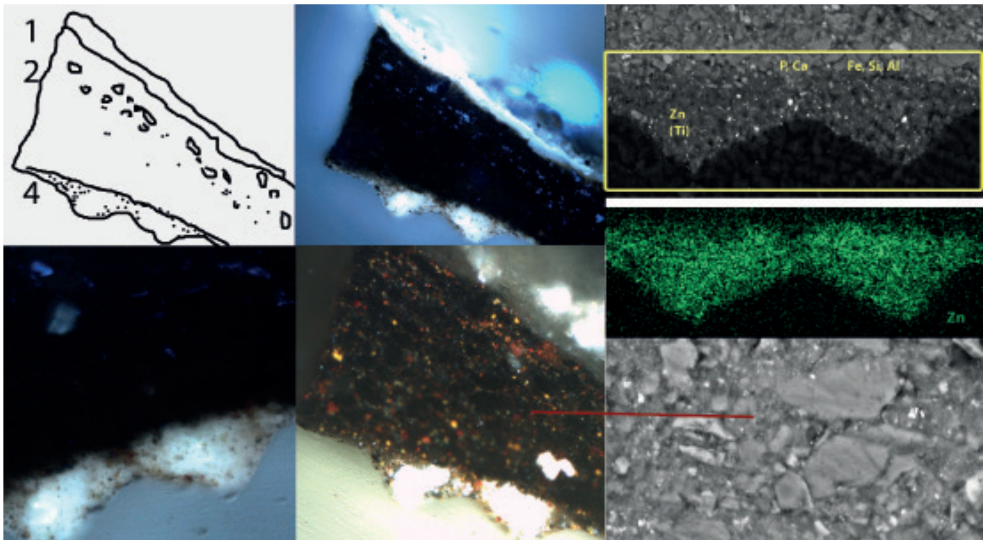


Figure 7. Illustration of a cross section from the upper layer of a delamination area, 1: Varnish/glaze, 2: Boneblack and red ochre, 4: Peaks of background colour/zinc soaps. SEM-EDX analysis of area in yellow square. Illustrations/ photo: Ida Bronken. SEM EDX: Calin Constantin Steindal.

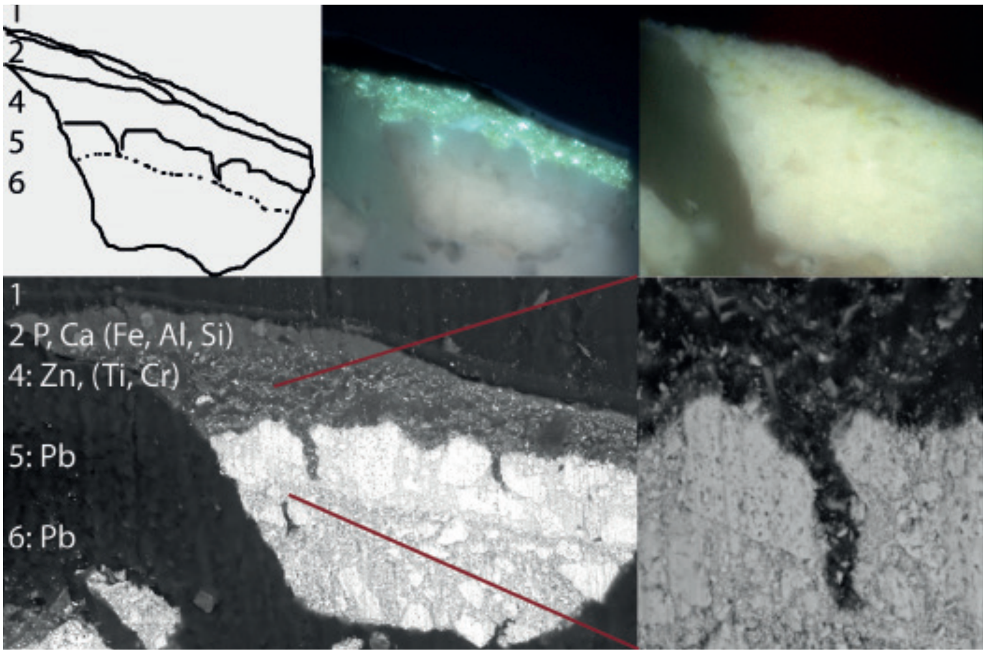


Figure 8. Cross section with the main layer structure from the edge of a black paint stroke. Clockwise from top left image: Layer illustration. Cross section in UV light. Cross section in normal light. Cross section in backscatter. Detail from crack in the ground. Illustration and photos from microscope: Ida Bronken. SEM-EDX images: Calin Constantin Steindal.

The cross-section from the edge of a black stroke shows that the ground has deep cracks, filled by the yellow paint of the background (Figure 8 and 9). This sample was taken close to the tacking edge, so the pre-primed ground might have cracked due to the mechanical action of attaching the canvas to the stretcher prior to painting. Without cross sections or other investigation of the ground further into the motif, it is impossible to know what the general surface structure was like before the application of the background colour.

Figure 8 shows that the interface between the lead white ground and the background colour in the cross-section near the tacking margin appears intact without any signs of mobile lead or the development of new compounds like soap pockets at the interface (Figure 9). This suggests that no delamination between the lead white ground and background paint is occurring in this area.

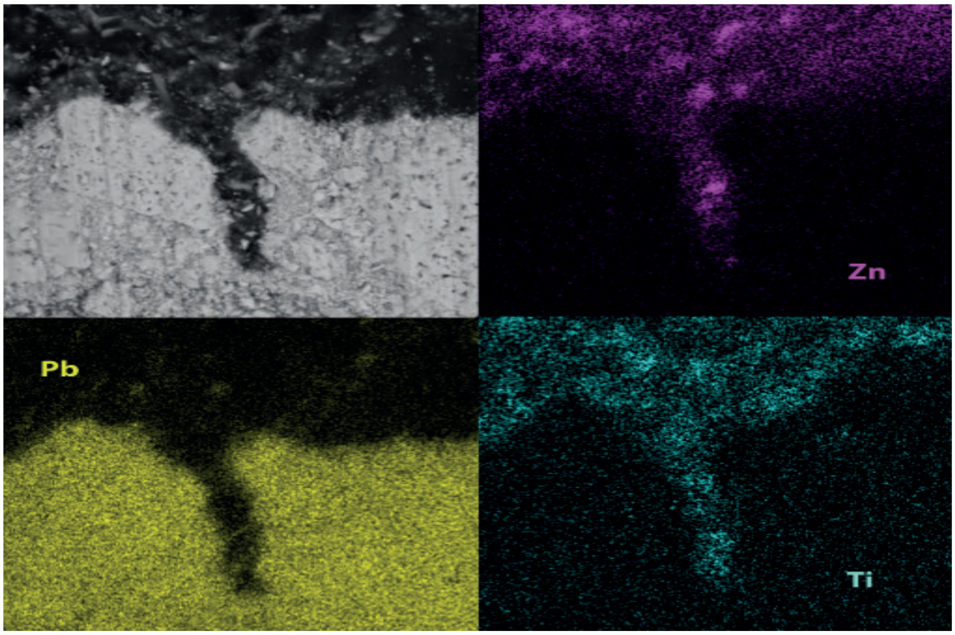


Figure 9. Map from the inter-phase between the ground and the background colour. SEM-EDX mapping: Calin Constantin Steindal.

## Chemical observations

A microsample from the dark upper paint layer kept in-between glass slides showed a ring of transparent organic material that oozed out of the paint. This sticky material, or exudate, was investigated with gas-chromatography mass spectrometry using online pyrolysis methylation by tetramethylammonium hydroxide (py- TMAH GC-MS) to obtain methylated fatty acid methyl esters (van Keulen, 2014). Mass spectra were identified using the atlas for oil paint compounds developed by J. van den Berg (2002). Figure 10 shows the total ion current chromatogram of the exudate. The numbers correspond to identified compounds listed in Table 1.

The main peaks in the chromatogram are the C8 (nr 8) and C9 diacids (nr 9) with smaller relative amounts of the C7 (nr 6) and C10 (nr 11) diacids. The distribution of these diacids suggest some form of thermal pre-polymerisation of the oil binder (Mills and White, 1999; van den Berg, 2002). Less intense are the peaks for palmitic acid (nr 13) and stearic acid (nr 15). Other peaks of interest are methoxylated glycerols (nr 1, 2, 3) where the diglyceride precursors are more prominent (nr 1 and 3). Further compounds of interest are unsaturated hydroxyl-stearic acids (nr 16, 17), (9,) 10-epoxy-stearic acid (nr 18) and the (9,10)-dihydroxy-stearic acid (nr 19, 20). We infer that these types of fatty acids and diacids, either free or partially bound as esters to glycerol, are the main compounds that penetrated from the upper black paint into the lower paints layers. An FTIR spectrum of the sticky material (Figure 10) shows the main absorptions at 1735 and 1712 $cm^{-1}$ indicative of glycerol esters and free acid groups (van der Weerd et al. 2005). Observations of soft paint in other case studies have shown that mobile fractions can move to other areas of the paint structure (Bronken, PhD thesis forthcoming). The hypothesis that the soft paint and its medium constituents is the root cause of the delamination is supported by an earlier published study on soap formation, which describes the relatively high fatty acid content of the soft paint (Bronken et al. 2019).

The level of hydrolysis in the black paint layer has not been determined analytically. It can be inferred that over time more fatty acids will become hydrolysed and free (Boon et al. 1997; van den Berg et al. 1999). It should therefore be a priority to monitor the condition, and development of the painting in this respect, in the future.

FTIR and GC-MS analysis of the black paint from *Peinture* point to a mobile phase of glycerol esters of saturated fatty acids and the various diacids observed. Similar compounds have been found in the binding medium of a Soulages painting from 1961 in the Sara Hilden Art museum in Tampere (Finland) where large delaminating areas have been

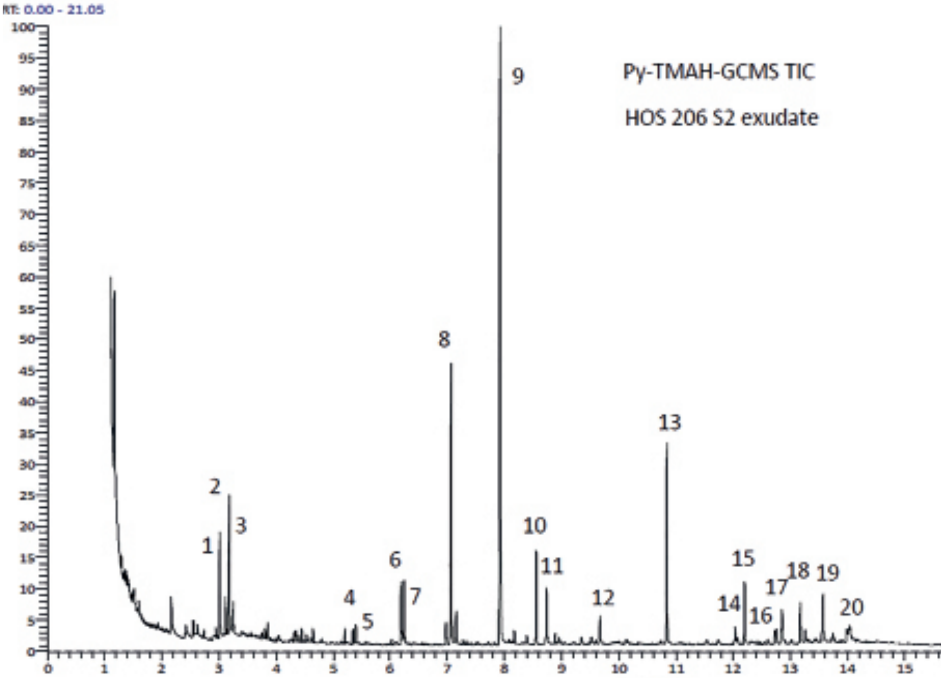


Figure 10. TIC (total ion current) profile generated from GC-MS data of the mobile transparent material exuding from the dark surface paint layer. GC-MS: Jaap Boon and Henk Van Keulen (RCE).

| Nr. | Chemical compounds | Abbreviations |
|---|---|---|
| 1 | 1,3-dimethoxy-2-propanol | GLY |
| 2 | 1,2,3-trimethoxy-propane | GLY |
| 3 | 2,3-dimethoxy-propanol | GLY |
| 4 | hexanedioic acid, dimethyl ester | C6 DF |
| 5 | decanoic acid, methyl ester | C10:0 F |
| 6 | heptanedioic acid, dimethyl ester | C7 DF |
| 7 | omega-oxo-octanoic acid, methyl ester | Oxo-C8 F |
| 8 | octanedioic acid, dimethyl ester | C8 DF |
| 9 | nonanedioic acid, dimethyl ester (azelaic acid) | C9 DF |
| 10 | tridecanoic acid, methyl ester (Internal Standard) | C13 F |
| 11 | decanedioic acid, dimethyl ester | C10 DF |
| 12 | alfa-methoxy decanedioic acid, dimethyl ester | OH-C10 DF |
| 13 | hexadecanoic acid, methyl ester (palmitic acid) | C16 F |
| 14 | octadecenoic acid, methyl ester (cis/trans) | C18:1 F |
| 15 | octadecanoic acid, methyl ester (stearic acid) | C18 F |
| 16 | 11-methoxy-9-octadecenoic acid, methyl ester | OH-C18:1 F |
| 17 | 10-methoxy-8-octadecenoic acid, methyl ester<br>9-methoxy-10-octadecenoic acid, methyl ester | OH-C18:1 F |
| 18 | 9,10-epoxy-octadecanoic acid, methyl ester | Epoxy-C18 F |
| 19 | 9,10-dimethoxy-octadecanoic acid, methyl ester | diOH-C18 F |
| 20 | 9,10-dihydroxy-octadecanoic acid, methyl ester | diOH-C18 F |

Table 1. Identified chemical compounds in Py-TMAH-GC-MS data of an exudate sampled from black paint of *Peinture* by Pierre Soulages.

Abbreviations:
F = fatty acid,
DF = diacid,
GLY = glyceride

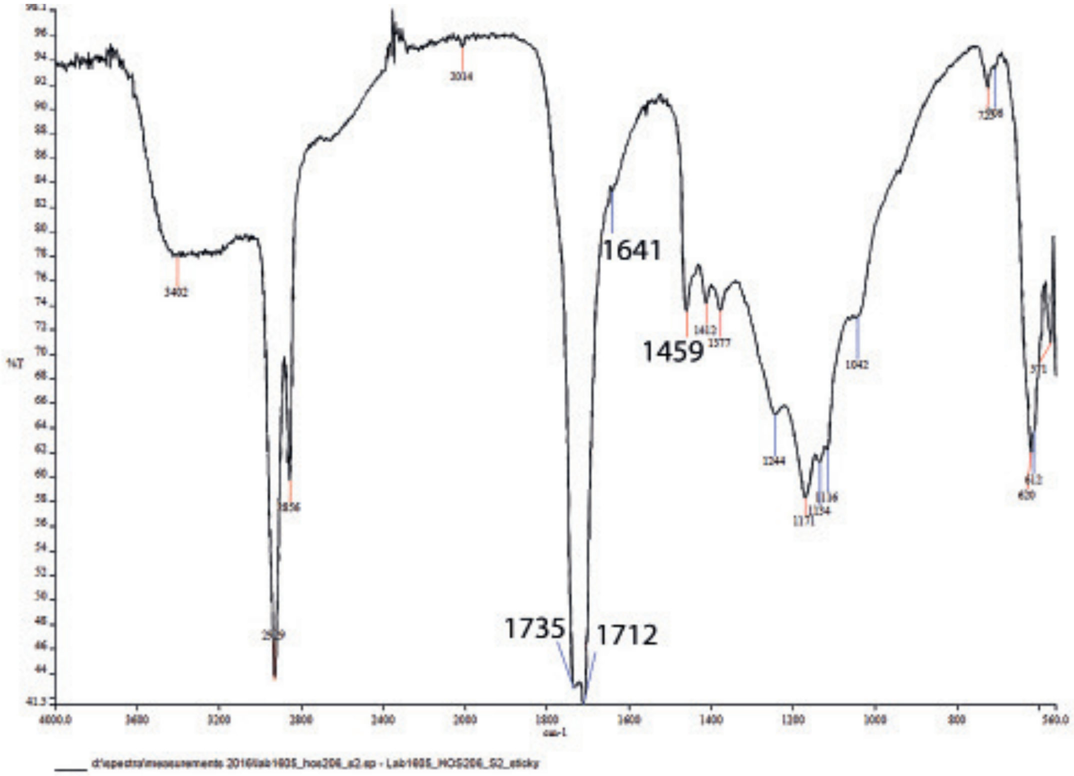


Figure 11. FTIR spectra of transparent exudate from the dark paint layer confirming the presence of glycerol-esters of fatty acids and diacids. Spectra: Karen Wyss, The Swiss Institute for Art Research Lab (SIK-ISEA).

investigated (Helou-de la Grandière et al. 2021) with MS and FTIR imaging. These compounds were also found to play a role in the softening of paints, and even in exudate formation in paintings by Riopelle (Bronken and Boon 2014; 2015) in which they turned into metal soaps linked to the delamination of the paints (Bronken PhD thesis, forthcoming). To investigate the hypothesis whether metal soap formation could play a role in the lifting of paint in *Peinture* various microsamples were obtained from within the delaminated area for study with attenuated total reflection FTIR (ATR-FTIR). Figure 12 shows the sampling locations in the paint layer diagram together with partial FTIR spectra of A, B, C and D. All spectra show CH vibrational features in the 2900 $cm^{-1}$ range typical for long aliphatic chains of fatty acids (not shown). Spectral features at 1737-1731 $cm^{-1}$ are indicative for glyceryl esters typically found in paint binding oils. The features near 1710 $cm^{-1}$ are indicative of carboxylic acid groups (van der Weerd et al. 2005). The features between 1600 and 1500 $cm^{-1}$ point to metal soaps (van der Weerd 2004; Osmond 2014; Hermans 2017). The FTIR spectrum of a sample (A) from an area without delamination displays small peaks that could be indicative of zinc soaps (Hermans 2017, Osmond 2014). Sample A is multi-layered, but without the soft black paint layer (numbered 2 in the illustration) (Figure 12). Sample B taken from exposed ground in an area with delamination shows a similar profile to sample A (Figure 11). Sample (C) was taken from a residue of the background colour in a delamination area, still connected to the ground. The peaks in the soap region are distinctly higher in this sample. The double peaks in the absorption region of 1550 to 1530 $cm^{-1}$ in A, B and C match the spectrum of a zinc azelate reference (Osmond 2014). This would correlate to the high peaks of azelaic and related diacids in the black paint layer (Figure 10). Recent studies by Hermans and Helwig (2020) point out that crystalline zinc soaps of long chain fatty acids (type A) will also show a double peak but the saturated fatty acids have a low relative concentration in the mobile phase originating from the black paint layer. Sample D was taken from the upper part of a delaminated area and only the light yellow uneven surface was analysed.

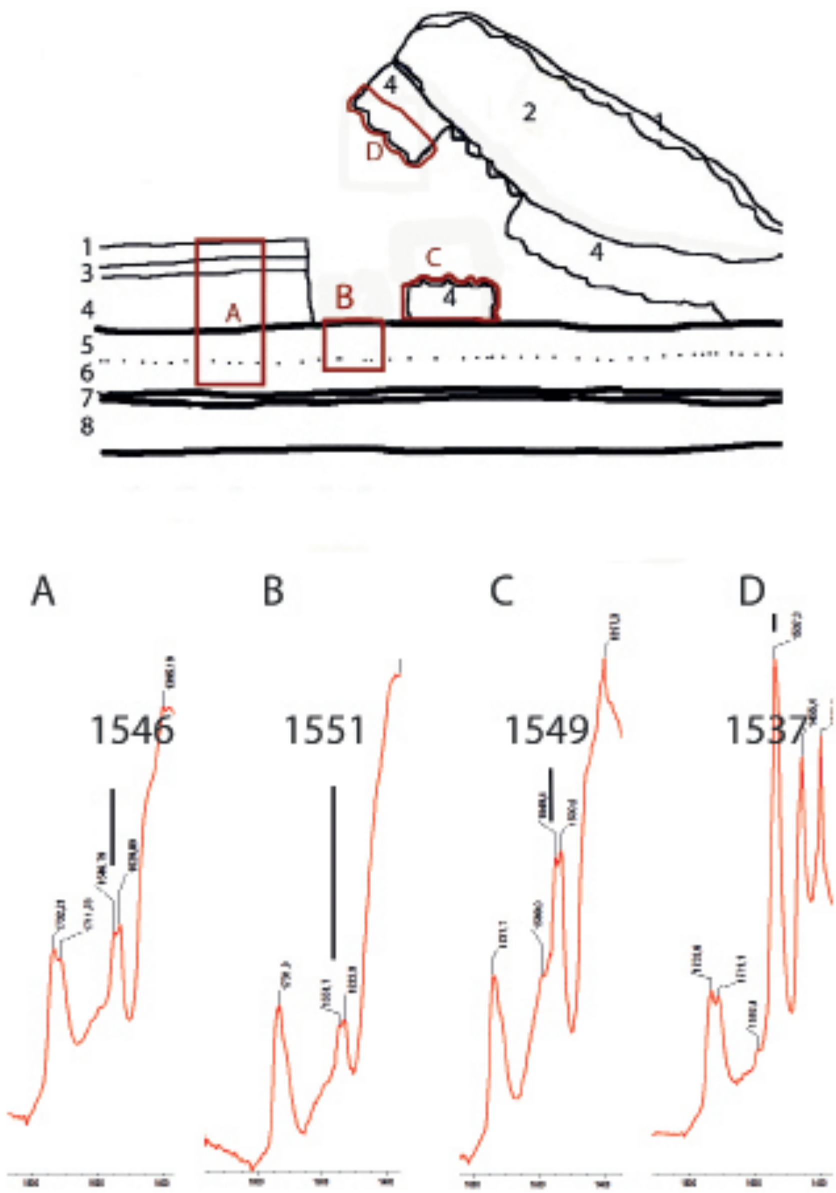


Figure 12. Simplified diagram of the layer structure and the position in the layer structure of sampling for the ATR-FTIR analysis. Details from the FTIR spectra focusing on the range with peaks indicative of soap formation. Illustration: Ida Bronken. Spectra: Calin Constantin Steindal.

The FTIR of D shows an absorption band of high intensity with a maximum at 1537 $cm^{-1}$, typical for zinc soaps of saturated fatty acids (the type B of Hermans and Helwig 2020). The sampling area is indeed rich in Zn as the EDX map shows (Figure 7). We infer that a high proportion of these type A metal soaps developed in area D near the interface. In general, the formation of zinc soaps will have weakened the interface leading to a loss of adhesion with delamination as a result due to the increase in volume and changes in rheology.

## Discussion

In order for metal soaps to form both fatty acids and metal ions need to be present in the paint structure. Analysis of the main layers in Peinture has shown

that the upper soft black paint has a surplus of oxidised oil derived materials, but minimal soap formation (Figure 10 and 11). It is not known how many fatty acids were hydrolyzed from the glycerol esters, but over time this will, in theory, increase, and contribute to some extent in creating additional mobile fractions. In the underlying structure, there should be an abundance of metal ions from the lead- and zinc-containing pigments (Figure 8). The study has identified clear differences regarding soap formation in the delaminating areas and in the stable paint areas (Figure 12, C, D and A). In the samples from the delamination area, there are double peaks indicative of azelaic zinc soaps possibly in combination with type A soaps of saturated fatty acids. In layer D a sharp peak indicative of crystalline palmitic and stearic acid soaps of the B type are present (Hermans and Helwig 2020).
There are clearly less soaps in the paint layers that are not covered with the soft black paint (Figure 12 A). This supports the hypothesis that the soap formation is more active at the extended interface between the background colour and the soft black paint.

We cannot dismiss the possibility that some fatty acids from the ground and the background paint itself might have contributed to some extent to the soap formation. The soft black paint definitely creates a more reactive interface as shown by the FTIR spectra and the py-GC-MS analysis. These results support the assumption raised in earlier studies by Rogala et al. (2010) and Helou-de la Grandière et al. (2008) on delaminations and their relationship to the degradation issues of either malleable or fatty acid rich layers. The findings uphold how important it is to understand the build-up of a painting and of the combination of materials. The first hypothesis that the delamination could be due to lead soaps was found to be incorrect. The intermediate zinc containing paint layer played a much more active role than anticipated.

It would be interesting to follow up this study with an investigation of the transparent web pattern on the ground with FTIR. Without further analysis, it is not clear if this material has developed into soap or not, but we can still speculate that this transparent web will not improve the adhesion in the layer structure. Whatever the local chemistry in the web pattern, we infer that it is part of the reason for an increase in delamination of the upper paint layers. This, together with the volume increase in the zinc soaps, will weaken the contact between the paint layers and push them apart.

Severe delaminations have been observed in Soulages paintings in Norwegian and Finnish collections (Helou-de la Grandière et al. 2021). Mobility within the paint and the development of soaps are believed to increase with higher relative humidity (RH) (Noble 2019). Another factor is the intrinsic instability of already developed soaps or mobile fractions that could have been formed in the layer structure. It is important to provide a stable climate with as little physical stress to the structure as possible. First instincts will therefore be to glaze the painting, and thereby minimize the risks for the structure. This is not a straightforward decision to make though. With what we know about the artistic intent, it is not optimal to glaze the painting. For the right viewing conditions of the surface other options must be discussed. If possible, the overall museum environment should be considered. Many museum collections are opening the outer parameter of their relative humidity control, allowing up to 60% RH (Ashley-Smith et al. 2013). This raises the question whether some degradation processes of modern paintings might possibly react faster with higher RH. Over time, do we know enough about to what extent the gain for a cut in energy consumption is weighted against a potential loss of the cultural heritage value of modern paintings? How much might the chemical process be accelerated at higher relative humidity or the increase in conservation treatments? It is probably impossible to answer this without more research. But it is undoubtedly an important aspect of providing optimal preservation for years to come. Multidisciplinary research should be a guide in discussions about optimal preservation of modern paintings in the future.

If there is suspicion of soft and sensitive oil paints, it will be beneficial to look at both the storage situation and climatic conditions. Is it possible to lower the general humidity in the museum below or to 50% to lessen the risk of increased soap formation and hydrolysis? If the paint has a tacky surface it will be beneficial to provide a dust protection in storage. This will minimize the need to dust the surface to prevent the dust particles slowly embedding into the upper paint layer. These measures might lessen the need for adding optium or other type of glazing to the frame.

## Conclusion

This case study has shown that zinc soap formation at the interfaces to the zinc white layer has led to delamination, primarily away from the ground. The fact that delamination is only occurring in regions with a black upper paint layer, suggests that the black paint is playing a role. This paint was found to be pigmented with bone black and ochre, it was soft and poorly cross-linked. The mobile acidic fatty acid content of the black paint is thought to be the main factor contributing to the zinc soap formation. This type of case study enhances our understanding of the particular combination of original paint properties and those developing upon maturation that influence the layer adhesion. Delamination is a severe and degrading condition of the painting surface that should be limited if appropriate museum conditions are chosen, particularly for modern art collections. Our recommendation is to consider the overall climate in the museum and communicate widely to all the museum staff both why and how sensitive the layer structure of similar modern paintings can be.

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## Experimental

**Fourier Transform Infrared spectroscopy (FTIR)**
FTIR spectroscopy measurements at the University of Oslo facilities were carried out in attenuated total reflectance (ATR) with a IS50 Thermo scientific Nicolet continuum FTIR microscope equipped with a Ge crystal with a resolution of 4 cm−1. Spectra were collected using 32 scans from 4000 to 400 cm-1.

**Scanning electron microscopy energy dispersive X-ray spectroscopy (SEM-EDX).**
A FEI Quanta 450 scanning microscope coupled to an X-MaxN Oxford analyser 50mm2 was used for SEM–EDX. Paint samples were embedded in Technovit 2000 LC, and dry polished.

**Pyrolysis- tetramethylammonium hydroxide -gas chromatography-mass spectrometry (Py-TMAH-GC-MS)**
The pyrolysis-TMAH-gas chromatography-mass spectrometry analyses were performed on a Thermo Quest GC-8000 equipped with a Supelco column Equity®-5, Capillary GC column 30m, I.D. 0.25mm, df 0.5 interfaced with a MS MD-800 (Keulen, van 2014).

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