Cultural Heritage Agency
Ministry of Education, Culture and Science

Consolidation of Paint and Ground

Paintings conservation

Consolidation of Paint and Ground

Paintings conservation Part 3

The 'Inherent vice' of materials refers to objects, which, due to the nature of their composition, are subject to deterioration in handling and over time or even degradation.[1]

My works are not intended for eternity, they'll wear themselves out and land back on the garbage heap whence they came – Jean Tinguely[2]

Pietro Edwards defines the 'original vices' of the work: 'Under this generic aspect (time), that comprehends nothing more of the cause of corrosion of painted things and that precedes the dissolution of all (things) constituted'.[3]

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1 *See:* https://www.nps.gov/museum/publications/MHI/CHAPTER4.pdf *page 4.7*

2 *quoted from:* https://www.bbc.com/culture/article/20220722-inherent-vice-the-masterpieces-that-decay *as part of interview :* https://www.getty.edu/publications/keepitmoving/keynotes/1-bek/

3 *Edwards, P. 1785, MS 787.6-876.7/10, Dissertazione preliminare al piano di custodia da istuirsi per la possibile preservazione, e per il miglior mantenimento delle pub.che. pitture, 1785, S.P.V. Quoted in: Darrow E., Necessity Introduced These Arts: Pietro Edwards and the Restoration of the Public Pictures of Venice 1778-1819*

SRAL
The conservation institute

SCI | Foundation for Cultural Inventory

Colophon

Consolidation of Paint and Ground

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Foreword

Welcome to one of six brochures created for professional conservators of easel paintings, wishing to keep up with current knowledge, and learning how to apply new techniques in their field. The brochures in this series are:

1. Dirt and Dirt Removal
2. Varnish Removal
3. Consolidation of Flaking Paint
4. Filling Losses in Paint
5. Structural Conservation of Canvas and Panels
6. Varnishing and Inpainting/Retouching

These brochures were compiled to serve as a reference, bringing together current practices and new knowledge regarding materials and methods for practical use. The content provided can be used by professional conservators, who are aware of the ethical and contextual aspects and complexity of conservation decision-making.

Conservation knowledge and practice are developing at an increasingly fast pace. In many countries, this knowledge is often concentrated within a relatively small group of conservators and other professionals in larger institutions with the resources to take major steps in the development and application of new methods for preservation and treatment of paintings.
New publications on focus topics are often issued through journals or editions that are costly and not easily available to the conservation field. Thus, accessing such knowledge and integrating into practice can be challenging. These brochures are designed to help bridge this gap. They are also a tool for mid-career professional conservators seeking to refresh and update their knowledge. The content is intended as a snapshot of up-to-date developments in these six focus areas and should not replace academic training in the field of painting conservation.

The need for this reference material became apparent during a series of masterclasses and conferences organised by the Foundation for Cultural Inventory (SCI) in India, Russia and Cuba, together with the SRAL-The Conservation Institute, the Cultural Heritage Agency of the Netherlands (RCE) and Dutch embassies in partner countries. These gatherings, focussing on the mutual exchange and deepening of knowledge in relation to local context and practices, were held under the auspices of the Shared Cultural Heritage programme.

This programme has since been succeeded by the International Heritage Cooperation programme, which more than ever emphasises the comparable societal challenges countries face and the value of the exchange of learning and knowledge to address contemporary issues in conservation. These brochures show how much can be achieved through mutual exchange and understanding.

We are providing this reference material in the hope and anticipation that it will assist conservators of easel paintings in their work in all geographical areas, so that future generations can continue to enjoy their international heritage for a long time to come.

We thank Conservation Scientist René Peschar (University of Amsterdam) and Senior Paintings Conservator Louise Wijnberg for their valuable input.

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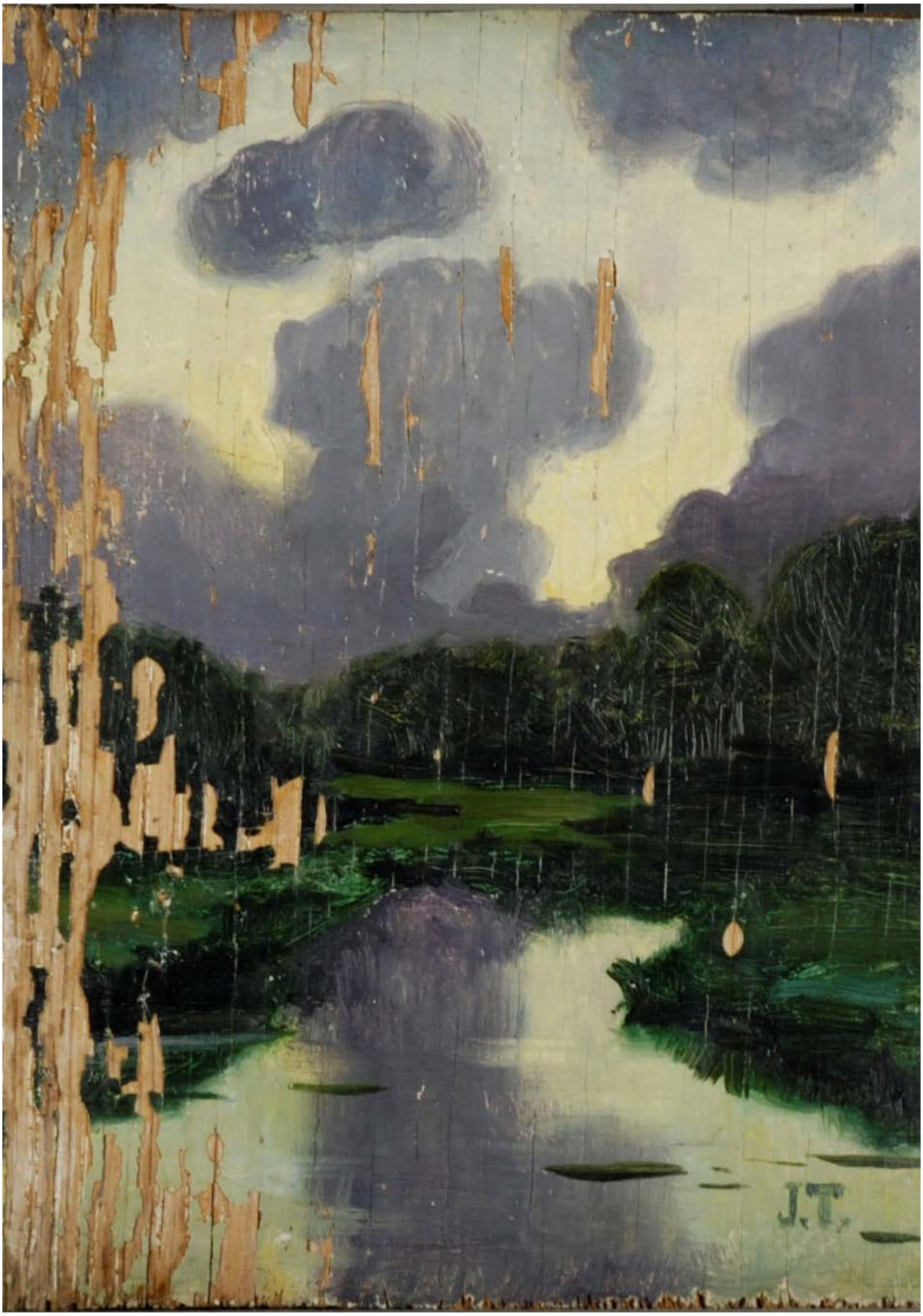


Detail Image of: J. Tielens (1886-1957), *Forrest view with pond*, oil on panel, (20 x 17 cm) showing large losses in both the paint and ground layers, various types of cracking as a result of both the mechanical properties of the paint layers and differences in reactions to environmental conditions of the paint, ground and substrate. Collection of the Cultural Heritage Agency of the Netherlands, Nr. E556

Introduction

Paintings, in most forms, consist of strata. Over the centuries, artists have used many different support typologies for their creations, including stone, wood, paper, metal and canvas. Once selected, the support is prepared, depending on their typology and artistic practice, to receive the subsequent decorative and artistic layers and coatings. This process creates a complex, heterogenous laminate structure with each material, strata and interaction thereof, adding to the chemical-physical-mechanical behaviour of the artwork as a whole. All materials are inherently subject to deterioration, and each has its own deterioration pathway. Furthermore, these materials and strata (layers) often have very different, even opposing, responses to external stresses and loads applied. This complex inter-play between strata may expedite damage, especially inter-laminar, under certain conditions. Such damage requires consolidation or re-adherence to prevent extensive or total loss. The process of consolidation is therefore complex and involves an understanding of physical, chemical and mechanical properties. While the treatment action may be similar for these diverse typologies, the materials used to consolidate, and the methods employed, may need specific or individual adjustments.

As each layer in a painting (support, ground, paint layers and coatings, see *Diagram 1*) has its own mechanical, physical and chemical complexities, and thus its own inherent vice, the damage that results over time, will manifest in specific often distinctive manner. Inter-laminate adhesion or internal cohesion may deteriorate. The materialisation of damage may be exasperated by internal degradation processes of the materials used by the artist or subsequently applied in past conservation campaigns. It can also be caused by interaction of the constituent materials with external factors such as relative humidity, temperature or pollutants. Degradation processes and environmental conditions may, therefore, cause inter-laminate splitting or delamination, cleaving, powdering, or even loss of adhesion, according to the resistance of the constituent materials to these factors.

Damage may become so severe that (localised) treatment is required to secure or restore stability in one or all of the layers of a painting, either locally or throughout the entire painted surface. This process is often called **consolidation**. The action of consolidation, or re-adherence of flaking or damaged paint to substrates, has not received considerable attention over the past two decades. While considerable publications address the use of adhesives in conservation practice, few focus on the act of consolidation.[4] This brochure aims to bring together the scattered information into one bundle that will deal with the ethical considerations, the degradation patterns leading to the necessity to consolidate, the concurrent treatments required to successfully apply consolidation, and the materials and tools needed by the conservator to carry out consolidation. This brochure also aims to provide guidance to the easel painting conservator selecting current best practice methods and materials for consolidation and re-adhesion of damaged paint layers.

[4] One exception is the CESMAR 7 conference on consolidation: The care of painted surfaces: materials and methods for consolidation, and scientific methods to evaluate their effectiveness: proceedings of the conference, Milan, November 10-11, 2006 https://www.cesmar7.org/congresso-colore-e-conservazione/ed-2006/
See also: Ploeger, R., Del Grosso, C., Poulis, J. *et al.* Consolidating Adhesive Project. *MRS Advances* 2, 1731–1741 (2017). https://doi.org/10.1557/adv.2017.243

Stratigraphy of a painting

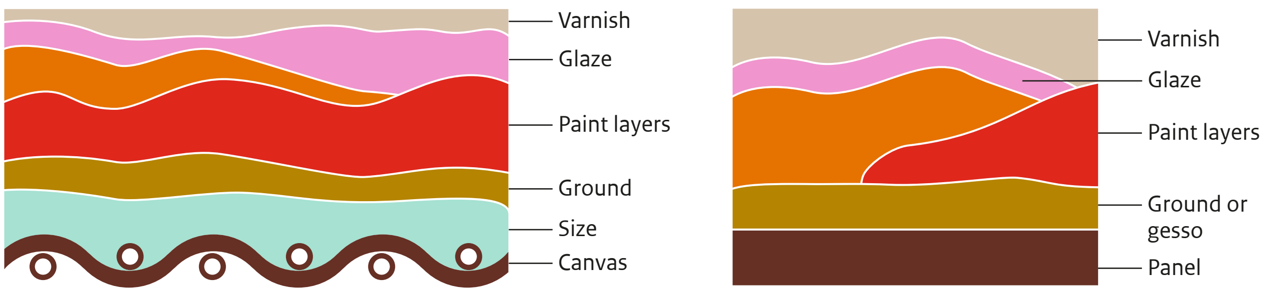


Diagram 1 showing the different strata in a canvas and panel painting, including the substrate, ground, paint and coatings.

Detail image of: S. van den Berg, *Composition* 1, 1977, acrylic on canvas, 62 x 75.5 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. BK25250. Localised exposure to excessive moisture has caused the canvas to shrink and deform, resulting in tenting paint. Seen in raking light.

Ethical Considerations for Consolidation Treatments

One of the most cited ethical concepts of contemporary conservation philosophy is the principle of reversibility. However, as the applied consolidant penetrates between layers or into porous substrates, the principle of reversibility is unattainable when consolidating. Adhesives, introduced to consolidate powdery pigment, or under flakes of paint, are not able to be removed without causing further damage and loss. Once applied these materials are 'there to stay' and it is thus essential to consider the longevity of treatment when selecting the adhesive. Adhesives that are stable chemically and physically overtime have preference over those which have easy handling properties. Therefore, more recent discussions have shifted this perspective towards re-treatability. Thermoplastic adhesives or glues with a stable solubility potential should be considered.
This allows for future re-treatability or reactivation of the adhesive. Contemporary conservators have a wider variety of adhesives for consolidation than those of generations past, meaning the pros and cons of various adhesives can be considered.

The irreversibility of consolidants increasingly became an issue following the extensive use of waxes and wax-resin adhesives for consolidation and lining before the mid-twentieth century. Paintings that had been infused with wax(-resin), either as part of a lining treatment or as part of a simultaneous lining and consolidation treatment, were found to be difficult to (re)treat with aqueous adhesives to prevent further, reoccurring flaking. [5] Many modern and contemporary artists' preferences for matte and underbound paint further challenged consolidation practice in the later twentieth century, since consolidants can significantly change the visual appearance of such paints, especially if tide marks or a change in gloss of the surface are undesired.

Since the 1970's, consolidation treatments of flaking paint have aimed to use materials compatible with the original paint and ground layers that allow for future re-treatments, rather than trying to aim for reversibility.[6] The guiding principles for consolidation treatments are that the method and materials used will suit the original materials and not alter the physical appearance of the materials, nor harm them. For example, matte adhesives should be considered for paint and ground layers that were intentionally made matte (often also unvarnished) by the artist.

Overview of Siep van den Berg (1913-1998), *Composition*, 1958, leeched oil on canvas, (90 x 70 cm). Many artists in the late nineteenth and twentieth century preferred a matte aesthetic and left their paintings unvarnished, such as this work by Siep van den Berg. Collection of the Cultural Heritage Agency of the Netherlands, Nr. SZ13370.

5 Wax-resin linings and consolidation treatments were also found to have darkened the paint and ground layers, irreversibly changing the tonality of paintings and also adding a gloss. Te Marvelde M., Wax-resin lining (chapter 25.4) in: Hill Stoner, J., Rushfield, R., (eds.) *The Conservation of Easel Paintings*, 2021 (2nd ed.) pp 451

6 Von der Goltz, M., Birkenbeul, I., Horovitz, I., Blewett, M., Dolgikh I., Consolidation of Flaking paint and ground' in: Hill Stoner, J., Rushfield, R., (eds.) *The Conservation of Easel Paintings*, 2021 (2nd ed.) pp 389-405

Detail image of: L. Swaanswijk, *Bird*, 1960, oil on canvas, 70 x 80 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. AB18681. The artist has applied a thick layer of paint over an earlier paint layer, one of many pentimenti in this painting. The top layer of paint has delaminated from the lower layers and flaked off.

Historical Approaches to Consolidation

Paintings presenting local damage phenomena, such as tears, were previously repaired in past centuries by cementing or (re)gluing patches to the reverse, (often) brushing away any flakes of paint that were detaching, and subsequently filling areas of losses and repainting the missing image elements.[7] A careful consideration for the historical value of damaged and detaching original material did not come into play until the twentieth century. Adhesives used were often applied without finesse, generally to a wider surface than required. Endemic or more widespread paint detachment was resolved through lining, attaching a secondary canvas to the reverse of the original support, with adhesives that impregnated all substrata. The materials and methods used often created, if not in the short term, more damage or degradation and frequently require retreatment at a later date. The general principles and materials used historically for consolidation are outlined in this chapter.

Historically, lining a painting was often used as a treatment for consolidating paint, and as a preventative measure for paint loss. Image: Rembrandt's The Nightwatch receiving a wax-resin lining in 1975. Image source: *https://kunstenaarsmateriaal.nl/km-artikelen/ongewenste-gevolgen-van-was-hars-bedoekingen/*

Past Techniques and Materials

All strata of the painting, from support to paint layers, were frequently treated in one action simultaneously. These treatments included impregnation, infusion, transfer to another support, lining and regeneration of layers. Local consolidation was rarely performed as such a refined technique was not considered essential. As the image was valued above its materiality, losses were repainted and thus loose paint was often brushed away and replaced. Respect for original materials became more evident in the eighteenth century and the evolution of consolidation treatments in Europe stems from this period.

Consolidation, practiced as part of the glue-paste lining method, often involved the use of an aqueous animal glue[8], called 'colletta', applied from the reverse through the original canvas. This adhesive was applied as an overall treatment to remedy endemic flaking issues prior to lining, typically with the canvas in tension. Natural animal glues, such as rabbit skin glue, isinglass, sturgeon glue and gelatines, were employed as useful consolidants.[9] If used with unskilled hands, the (excessive) heat, moisture and weight to aid the bond between the original and lining canvas (with the purposeful intention of simultaneously treating the paint and ground layers) can cause shrinkage of the support and lead to further paint loss. This often resulted in damage to these layers, through flattening of impasto, (localised) weave re-enforcement, softening of ground layers, and plastification of the oil medium.[10] Recipes for glue-paste consolidation and lining can be traced back to Giorgio Vasari, who advised artists on using the same mixture of flour and animal glue as for preparing grounds for canvases in his treatise *On Technique* and which was refined in the Napoleonic period when French and Italian

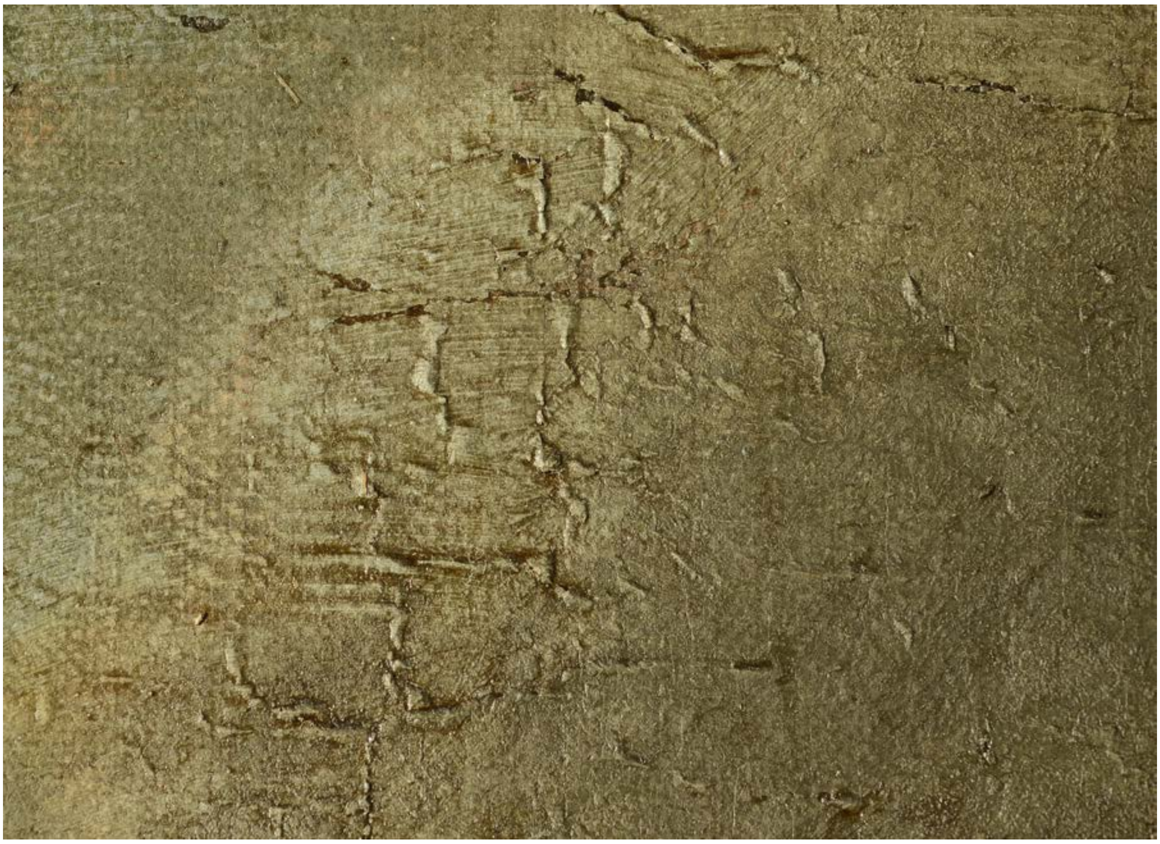
7 Wagner C., Arbeitsweisen und Anschauungen in der Gemälderestaurierung um 1800, Veröffentlichung des Instituts für Kunsttechnik und Konservierung im Germanischen Nationalmuseum, 1988, vol 2. Germanisches Nationalmuseum/Callwey

8 Animal glues, in this context, include skin glues such as rabbit or parchment glues such as goat.

9 The De Mayerne manuscript from the seventeenth century contains miscellaneous notes on the subject of artistic techniques, including the making of pigments, oils and varnishes, the priming and preparation of surfaces for painting, and the repair and conservation of paintings. *http://www.bl.uk/manuscripts/FullDisplay.aspx?ref=Sloane_MS_2052*
Von der Goltz, M., Birkenbeul, I., Horovitz, I., Blewett, M., Dolgikh I., Consolidation of Flaking paint and ground' in: Hill Stoner, J., Rushfield, R., (eds.) *The Conservation of Easel Paintings*, 2021 (2nd ed.) pp 390

10 Hackney, S., *Lining easel paintings*, In: Hill Stoner, J., Rushfield, R., (eds.) *The Conservation of Easel Paintings*, 2021 (1st ed.) pp 422-424

Excessive heat and moisture during a past lining treatment has resulted in weave reinforcement. Image: Anonymous Portrait, collection Oostwegel. Image source: Kate Seymour (SRAL).



Detail image of paint blistering due to excessive heat. Image source: Kate Seymour (SRAL).

restorers developed recipes and methods for lining canvas paintings in Paris and in Florence and Milan.[11]

Throughout history, animal glue has been the most commonly available adhesive. Animal glues have a large adhesive strength, and those made from bovine hooves, tendons and cartilages tend to be the strongest due to the high collagen content, although it is also the most brittle upon aging. Finer, more elastic but less adhesive glues come from the hides of smaller animals (such as rabbit-skin or goat-skin glues), and are generally more useful as a size or gelatines. Fish glues such as Sturgeon glue (also known as Isinglass) is a traditional adhesive made from the sturgeon bladder and is very strong and flexible. It is also commonly used for consolidation of flaking paint (although lower concentrations are used).[12]

Dried solid animal glues are soaked in water to swell and liquefy them. Collagen glues dry and form a film as a result of the solution cooling into a gel phase, through evaporation and by absorption of the water into the substrates. During this transition, the adhesive goes through a tacky phase, which requires slow, controlled cooling in order to create an effective adhesive bond. If too much water evaporates from the structure of the glue, it tends to overly solidify and become rigid. When excess water is retained, the film may become unstable. This means that relative humidity and temperature also play an important role in both the drying and the stability and effectiveness of the glue. As the glue cools and dries, animal glue has a tendency to shrink and contract. The amount of shrinkage is proportional to the amount of water in the glue. Additionally, the faster the glue loses water, the more pronounced the shrinkage.[13]

[11] Hoeniger C., The Development of Principles in Paintings Conservation: Case Studies from the Restoration of Raphael's Art, in: Bracker A., Richmond A., (eds.) *Conservation: Principles, dilemmas, and uncomfortable truths*, 2009 Issue 58 pp 100-112
Giorgio Vasari, *Le vite de' più eccellenti pittori scultori ed architettori* (1568) Gaetano Milanesi (ed), 9 vols (Florence: G.C. Sansoni, 1878–1885) Volume 4 (1879)
Vasari, Giorgio [1568] (1907): *Vasari on technique; being the introduction to the three arts of design, architecture, sculpture and painting, prefixed to the Lives of the most excellent painters, sculptors and architects.* Edition de Gerard Baldwin, London: J.M. Dent & Co

[12] Haupt M., Dyer D., Hanlan J., An investigation into three animal glues, *The Conservator* (1990) vol. 14 pp 10-16

[13] Masschelein-Kleiner L., *Ancient Binding Media, Varnishes and Adhesives*, ICCROM, 1985 *https://www.iccrom.org/publication/ancient-binding-media-varnishes-and-adhesives*

These patches were applied to the back of the canvas to help consolidate flaking paint on the front of the artwork.

The majority of liquid glue-paste lining formulations are meant to pass through the lining canvas from the back into the matrix of the painting., and therefore also the ground and paint layers. Glue-paste adhesives are applied at around 50-60 °C to both the reverse of the painting, and to the lining canvas. Depending on the viscosity, some are applied with a spatula, while others are poured on to the surface and spread using a variety of utensils to evenly apply the glue. The lining canvas is then placed in contact with the reverse of the original canvas before the adhesive has cooled, and pressure is applied to aid in the adherence of the lining canvas and canvas during cooling and drying/setting. Most glue-paste lining procedures require the use of heat and pressure to control and ensure a gradual loss and desorption of water. The condition of the original canvas will dictate its reaction to the lining procedure, depending on its age and condition it may shrink, causing the paint to tent. Therefore, pressure is necessary to maintain an overall flatness and ensure complete contact between the two surfaces.

Consolidation and lining also occur simultaneously in the wax-resin lining technique. The wax-resin adhesive functions as the consolidant aiming to reattach paint defects, especially flaking paint. The adhesive flows on heating and impregnates fully all strata from the original canvas to the paint layers. Heat plasticises the paint layers and encourages the adhesive to seep between the raised paint and support re-adhering the lifting paint flakes. Many tacky materials, such as waxes and resins, have been used in the past to consolidate flaking, cupping and lifting paint. Historical sources have noted the inclusion of drying oils, such as stand oil, linseed and poppy oils in various recipes. Wax-resin mixtures for consolidation and lining of paintings gained in popularity throughout the nineteenth and twentieth centuries, especially in the Low Countries where the climate ensured that aqueous linings did not have a long lifetime.[14]

Nicolas Hopman (1794-1870), who developed the technique in the mid-nineteenth century with his son Willem Antonij (1828-1910), was confronted with a situation in which water-related problems were threatening to destroy many paintings due to blistering of both the painting and ground layers. Hopman,

[14] Te Marvelde, M.M., The application of the wax-resin lining procedure and its effects on paintings. *In: MolArt: A multidisciplinary NOW Priority Project on Molecular aspects of Ageing in Painted Works of Art: Progress Report 2000*, (2001) pp 33-35 Nederlandse Organisatie voor Wetenschappelijk Onderzoek.

Historical irons being warmed on a traditional boiler oven prior to use for lining and consolidation. Image courtesy of Studio Giovanni Secco Suardo.

Glue paste used in lining. A mixture of animal glue and flour is applied to the reverse of the original canvas, which absorbs the moisture from the glue-paste mixture and transports it in to the strata of the painting, before slowly evaporating out during drying.

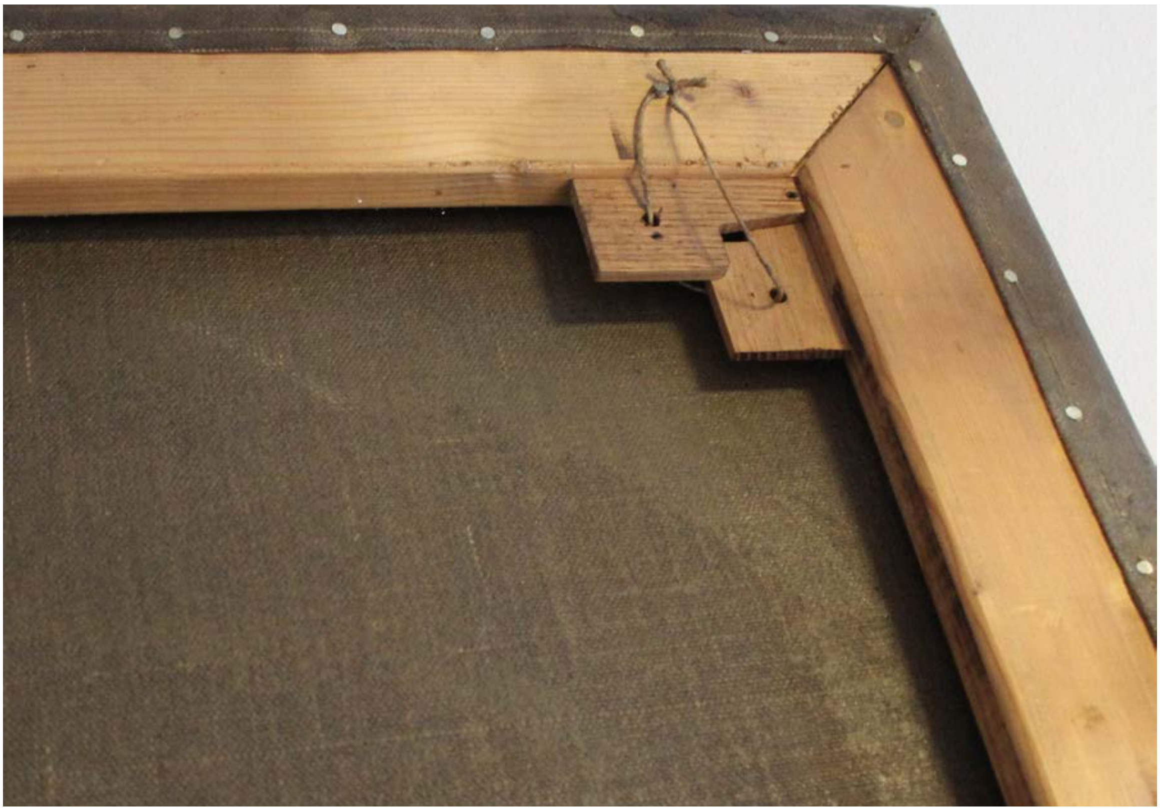
who was inspired by the (then) recent discoveries of many Egyptian objects that had been immersed in wax, or painted with wax-based paint, reasoned that beeswax was a suitable preservative medium that would repel moisture. The addition of colophony resin to the beeswax was to add adhesive strength to the wax. Research by Te Marvelde indicates that the wax-resin lining technique by these two restorers, who worked at, amongst other collections, the Mauritshuis in The Hague, and where examples of their lining technique can still be found in excellent condition, was used primarily to treat issues with the ground and paint layers, rather than canvas issues.[15] In any case, the simultaneous treatment of paint and ground when adding an additional canvas, occurs in the same action and was often seen as a preventive measure. Such linings were often carried out with such a mindset to combat multiple issues in one treatment. Heat used to apply these linings and excessive pressure, especially combined with the use of a hot vacuum table has caused irreparable damage to paintings.

The History of Synthetic Resins[16]

Synthetic resins were introduced in the late nineteenth century and had become common by the 1930s.[17]
Early synthetic resins, such as cellulose nitrate (produced as a coating or lacquer), were used seldom as a paint consolidant due to their difficult handling properties.[18]
However, some painted objects treated in the early days of production of synthetic (plastic) resins were consolidated with these highly unstable polymers.
The founders of the petroleum and chemical industry, such as Dow Chemical, ExxonMobil, DuPont, and BASF, began to produce more refined (plastic) resins by the early 1930s, that can be dissolved in solvents or emulsified in water and used as coatings or adhesives. These giants of the chemical companies are still the main manufacturers of raw material resins.

Most of these chemical companies have production centres distributed globally and, as they are commercial businesses, they are often subject to mergers or acquisition by competitors. Resins produced are frequently discontinued or subject to reformulation. Synthetic polymers used as consolidants were often manufactured for other purposes, such as coatings or vehicles for paints and inks. They were often sold under proprietary names, by which they are more commonly known in the conservation field. Different variants of the same polymer are often sold under one trademark name with numerical designations (for example there are many Plextol acrylic resins manufactured each with slightly

15 Te Marvelde, M.M., *Wax-resin Lining by Mireille te Marvelde*, in: in: Hill Stoner, J., Rushfield, R., (eds.) *The Conservation of Easel Paintings*, 2021 (1st ed.) pp 424-432
16 In conservation and restoration, synthetic polymers are often colloquially referred to as 'resins', though chemically this is not correct. The actual (tree-) resins are terpenoids.
17 *https://www.sciencemuseum.org.uk/objects-and-stories/chemistry/age-plastic-parkesine-pollution*
18 Cellulose nitrate is produced from cotton fibres dissolved in nitric and sulphuric acids then mixed with vegetable oil. The production of cellulose nitrate was patented by Alexander Parkes in 1862 as Parkesine.



Detail image of the reverse of a canvas that has been wax-resin lined. Excess wax-resin has been left on the reverse of the canvas, which can cause stiffness in the canvas and deformations where excess wax remains between the two canvasses.

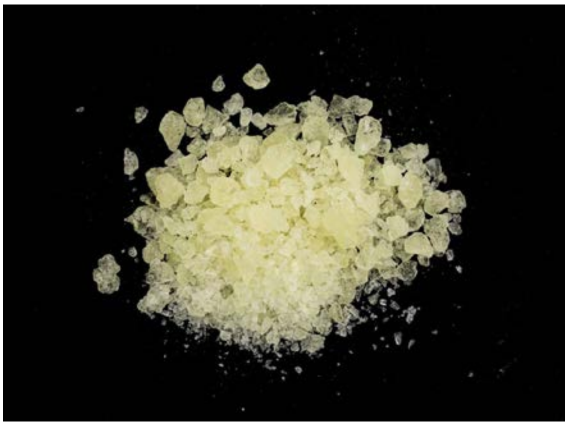
Lascaux Medium for Consolidation, a synthetic resin formulated especially for consolidating paint.

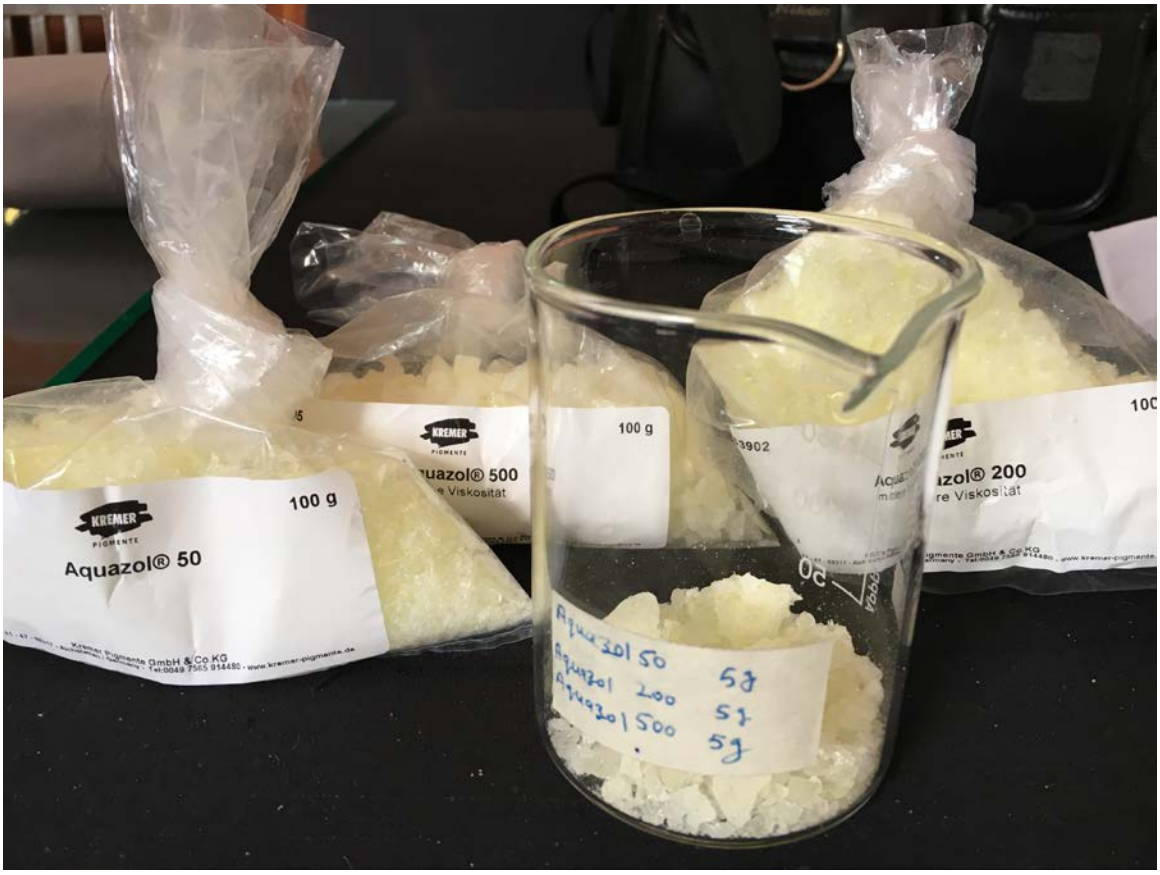
different properties of which only a few are used in the conservation field). Similar products manufactured by a competitor will be sold under a different name. This fact can lead to some confusion and occasionally preferential acquisition!

All synthetic resins are produced having different molecular weights which give divergent physical properties to the resins. **Lower molecular weight (LMW) equivalents of each resin type will be less viscous when prepared in a solution of the same concentration as the higher molecular weight (HMW) variant.** The glass transition temperature (Tg) of the LMW resins will be closer to room temperature and thus the resin coating will be more flexible at ambient temperatures, but also more susceptible to dirt pick up if applied or left on a surface.[19]

Both vinyl and acrylic polymers were being mass produced from the waste products derived from processing crude oil and natural gas by the mid 1930's. The vinyl and acrylic resins were originally formulated as raw solid states which could be dissolved in solvents,

[19] The glass transition temperature describes when a material transitions from a hard, glassy material, into a viscous, but pliable product.





Aquazol 200, a synthetic resin used for consolidation. (Image source: Kate Seymour, SRAL).

but can also be emulsified in water. The emulsification process to produce a water-based adhesive is complex and requires specialised laboratory equipment. Thus, while the raw solid state of these polymers can be purchased and dissolved in the studio, dispersions are more commonly bought ready-made off the shelf.

The British Company Imperial Chemical Industries (ICI) patented Perspex, a polymethyl methylacrylate (PMMA), in 1932. These high molecular weight (HMW) polymers produced viscous liquids when dissolved in solvents. The high viscosity inhibited flow and thus their properties were not suited for consolidation purposes. By the 1970s, modified PMMAs, such as Paraloid B67 (isobutyl methacrylate) and Paraloid B72 (a copolymer of ethyl methacrylate–methyl acrylate), found widespread use in the paint and coatings industry and subsequently in the conservation field.[20] Both can be dissolved and used as a binder or consolidant, particularly for delaminated oil, alkyd or acrylic paints. Other variants within the Paraloid family, such as Paraloid B66 or Paraloid N44, are used for consolidation of paint layers applied to metal surfaces. These adhesives are considered stable chemically, though some variants such as Paraloid B67 have a tendency to cross-link and become non-soluble and irreversible if used as a coating.

Dispersion acrylics were introduced in the 1950s under a wide variety of names and continue to be produced today by many manufactures in the coatings industry. The Plextol 'family' of dispersion acrylic adhesives (currently produced by a German manufacturer Synthomer) are well known to conservators worldwide, as are similar products, such as Lascaux 498 and 360 (HV) manufactured by Lascaux. These formulations contain surfactant additives and/or thickeners which maintain dispersion of the polymer in water, or modify the rheology of the dispersion. These polymer dispersions are used as paint vehicles and coatings. Modified formulations designed specifically for the conservation field, such as Lascaux's Medium for Consolidation, are used as consolidants because of their good penetration into substrates and ability to bind powdery paint. Acrylic dispersions are stable and UV resistant, however the surfactant additives may migrate especially from paints and their relatively low Tg's may encourage dirt pick-up.

Vinyl acetate-based polymers (PVA's) are commonly poly vinyl acetates (PVAc's), but several modifications can be available based on hydrolysis level (poly vinyl alcohols, PVAl or PVOH) or on copolymerisation procedures (e.g., copolymers of vinyl acetate and ethylene, VAE). These adhesives were also first introduced in the 1930s in solid raw format and later as emulsions. PVA's are available in different molecular weights varying from high to low. Vinyl acetate-based polymers are extremely versatile and form strong, flexible, adherent films that offer excellent adhesion to common substrates, such as wood, textile, or paper; they are also used commercially in construction products, carpet backing, paper and paperboard coatings, and engineered fabrics. Typical examples used in the conservation field are locally produced 'wood' glues bought at builder's merchants (for example Bison, Lineco, Jade or Elmer's Glue). Conservation grade adhesives in this family were produced under the trademark Mowilith, however the most commonly used variant Mowilith DMC2, which contained few surfactants and no thickener, is no longer produced. Currently, two low molecular weight PVAc's, or rather Ethylene Vinyl Acetates (EVA's), are produced for the conservation market and are used by paper and canvas conservators – these are BEVA D8 (developed by Gustave Berger, USA) and EVACON R (developed by Preservation Equipment, UK). Vinyl acetate-based adhesives are low cost to produce and are therefore readily available. They are polymers with good aging characteristics, but in some cases water sensitivity can be a problem. This is typically taken care of by formulating it with plasticizers to increase their reliability and stability. Additives may be included in the formulation of all forms of vinyl acetate-based adhesives in order to prolong shelf-life and inhibit foaming when brushing out. Cellulosic stabilisers may also be added, especially to the low viscosity variants.

Other synthetic resins such as poly(2-ethyl-2-oxazoline), known as Aquazol, and hydrogenated hydrocarbons, known as Regalrez, were introduced in the 1990's as consolidants, binders and coatings.[21] These polymers are dissolved from their solid state in solvents, the former is soluble in water and alcohols, while the latter is soluble in hydrocarbon solvents. Both resins have been used successfully in the conservation field as consolidants. Their relatively low molecular weight produces solutions of low viscosity at higher concentrations, meaning that less shrinkage occurs as the film forms. Their ability to flow into substrates has encouraged their use to consolidate powdery paint or paints with water sensitivity. Their solubility profiles and chemical stability mean that they remain soluble over time.

Methods and Instruments for Consolidation

Heat was commonly used to encourage adhesive flow, speed up the curing of the adhesive and softening paint layers during the consolidation process. In the past, restorers often had access to wide range of sizes of heated tools. Heat was applied by irons, spatulas or spoons, heated directly on a fire or in hot water baths. These heated instruments are not temperature controlled, therefore, if applied too hot, further damage could be caused during use. However, one benefit was

[20] Note that the proportions of this resin's copolymers shifted in the 1980s. Today it is a copolymer of ethyl methacrylate (70%) and methyl acrylate (30%). Paraloid B72 was formerly known as Acryloid B72 in the United States of America.

[21] Arslanoglu, J. 2005. *Using Aquazol: A brief summary*. In: AIC Paintings Specialty Group Postprints, 32nd Annual meeting. Portland, Oregon: 107-11.

Images of historical irons used for lining and consolidating canvasses. Images courtesy of Studio Giovanni Secco Suardo.

A modern ironing tool, used to consolidate paint

that the heated metal began to lose heat when removed from the heat source, and thus, when used by a skilled hand, these instruments could be manipulated with care and attention. Small hatters' irons or very heavy hand irons were often used for applying patches or lining. The smaller irons were utilised when applying adhesive locally. Other methods to apply heat were also used and included heated sand bags and beds or slate table tops.[22]

The introduction of electric irons and heated tables in the second quarter of the twentieth century allowed a more regulated approach to temperature control, but also allowed restorers to work continuously at a higher temperature.[23] Often these instruments presented uneven heat distribution and could only provide uniform heat at elevated temperatures. This excluded working at low temperatures.[24] Today, special temperature regulated, electrical hand-irons, mats and spatulas have been developed for the conservation field and can be bought for lining and consolidation purposes.[25] Recently, conservators have worked closely with engineers to develop heated mats that can be thermostatically controlled to provide a homogenous heat distribution at lower temperatures ranging from 30°C.[26] This increased accuracy, whether with small instruments or the electric mats, allows the conservator today to use heat judiciously in treatment methods.

The mis-use of temperature, especially when combined with pressure, has caused local blistering of paint, flattening of impastos, and moating (where harder paint areas such as impastos are pushed into the substructure). Scorch marks and paint blisters due to over-heating are frequently observed on paintings treated by heated hand tools. Damage can be further exacerbated when moisture is introduced into the treatment methodology. The use of aqueous adhesives, that require heat to induce flow and to speed up evaporation of the solvent (water), encouraged the plasticity of the paint layers. While this desired effect could be beneficial in flattening raised paint flakes and ensuring that the adhesive penetrated to the point of delamination, combined with pressure, paint layers could be softened and / or crushed. Blanching can be induced in the varnish layers, and even in the paint matrix, if present at time of treatment. Many paintings show evidence of these damage patterns.

[22] See: Chapter 6: Venice and Pietro Edwards, In: Conti A., A History of the Restoration and Conservation of Works of Art, 2007 (3rd ed.) Elsevier Ltd, The Boulevard, Langford Lane, England, pp 181-220
And: Darrow E., Pietro Edwards and the restoration of the public pictures of Venice, 1778-1819: necessity introduced these arts, 2000, *https://digital.lib.washington.edu/researchworks/handle/1773/6223* (pdf available).

[23] Von der Goltz, M., Birkenbeul, I., Horovitz, I., Blewett, M., Dolgikh I., Consolidation of Flaking paint and ground' in: Hill Stoner, J., Rushfield, R., (eds.) *The Conservation of Easel Paintings*, 2021 (1st ed.) pp 371

[24] BEVA 371 was designed with a melt temperature that was determined by the lowest minimum even temperature distribution of the hot table. The elevated Tg above room temperature was also beneficial.

[25] See: *https://www.willard.co.uk/hand-tools* and *https://ctsconservation.com/en/203-tools-and-accessories* for equipment designed especially for the field of conservation.

[26] See: *https://www.precision-mat.com/imat*

The laminate structure and its response to mechanical-physical forces

Considerable studies have been carried out which help conservators and those caring for collections to predict the environmentally driven, dimensional response of complex laminate structures that paintings consist of.[27] Common consensus acknowledges the role that each layer, and its constituent components, plays in the preservation of painted artworks. The following overview provides insight into the prime initiators and causes of related degradation phenomena and the painting's predisposition to cracking, sometimes called craquelure. The formation of craquelure is inherent and, while the effect can be mitigated through buffering the painting from fluctuating changes in relative humidity, is considered a part of the natural aging of the artwork.[28] Today treatments of paintings, especially canvases, incorporate the application of backing boards which act as buffering systems to mitigate moisture exchange. It is, therefore, recommended to place backing board systems as standard practice.

Supports may differ in materiality and, thus, also rigidity (paper, parchment, metal, wood, canvas, stone etc). These characteristics influence their physical properties and their response over time to applied forces and stresses. For instance, wooden supports will respond to fluctuations in relative humidity at a different rate and direction to canvas supports. Different wood species will manifest diverse stress patterns in superficial layers causing distinct crack patterns to form.[29] The choice of canvas fibre and weaving pattern will also influence the morphology of cracks in less flexible layers applied on top. Research has shown, however, that crack patterns will form consistently for objects made of similar materials using the same assembly methodology.[30] Research proposes that the distinct crack pattern can be used to determine manufacture typologies and regions. It is now understood that, while the support layer will change dimensionally when absorbing and desorbing water content, it is the mechanical response of other key layers in the painting laminate structure, in particular the preparation layers, that manifest in cracking and other stress related fractures.[31]

The support, whether paper, canvas or wood, is typically prepared by first applying a coating of animal glue (derived from mammalian collagen), which reduces its absorbent characteristics allowing the subsequent layers to form a distinct layer on the surface of the support without being imbibed. This sealant, called the **size layer**, has a strong impact on the rigidity of the multi-layered painting structure and the formation of cracks in the upper applied layers. It is also found frequently as the main binding component of the subsequent ground layers, especially in panel paintings. The **ground layers** are applied after sizing the support to create a smoother surface on which to paint. The composition of these layers differs according to support type, artistic practice, and geographical location. Ground layers on panel paintings in Northern Europe typically consist of calcium carbonate bound in animal glue, whereas those employed in Southern Europe are composed of calcium sulphate dihydrate, also bound in animal glue. Studies have shown that the use of animal glue as the binder is a key driver in the mechanical response of these layers to applied forces within the laminate structure.[32]

Animal glue has very opposing physical resistances dependent on its water content.[33] The drying of the film

[27] Michalski S., Paintings: their response to temperature, relative humidity, shock, and vibration. In: Mecklenburg FM, editor. *Art in Transit: studies in the transport of paintings*, Washington DC: National Gallery of Art; 1991. p. 223–48 *https://www.academia.edu/741944/1991_Paintings_-_Their_Response_to_Temperature_Relative_Humidity_Shock_and_Vibration*
Michalski S., Risk analysis of backing boards for paintings: damp climates vs. cold climates. In: *Minimo Intervento Conservativo Nel Restauro Dei Dipinti: Atti Del Convegno*, Thiene (VI), 29–30 Ottobre 2004: Secondo Congresso Internazionale: Colore E Conservazione, Materiali E Metode Nel Restauro Delle Opere Policromi Mobili. CESMAR7: The Center for the Study of Materials for Restoration. Padua: Il Prato, 2005. p. 21–27.
Hartin, D.D., Backing Boards for Paintings on Canvas – Canadian Conservation Institute (CCI) Notes 2016;10/10. *https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/canadian-conservation-institute-notes/backing-boards-paintings.html*
Vila A., Murray A., Andersen C.K., Izzo F.C., Fuster-López L., Aguado-Guardiola E., Jiménez-Garnica R., Scharff A. Picasso 1917: An insight into the effects of ground and canvas in the failure mechanisms in four Artworks. *Conservation of Modern Oil Paintings*, 1917; 2019 pp 245–53

[28] Padfield, T., Padfield, N., Lee, D.SH. *et al.* Back protection of canvas paintings. *Heritage Science* Vol. 8, Nr. 96 2020 pp *https://doi.org/10.1186/s40494-020-00435-7* (available as pdf).

[29] Bucklow S., Classification of craquelure, chapter 16. In: Hill Stoner J, Rushfield R (eds) *The Conservation of Easel Paintings: principles and practice*, 2012, Butterworth-Heinemann, London/New York, pp 285–290
And: Bucklow S., The Classification of Craquelure, Hamilton Kerr Institute Bulletin, Nr 6, *https://www.hki.fitzmuseum.cam.ac.uk/projects/cracks2*

[30] Bucklow S. The description of craquelure patterns. *Studies in Conservation*, 1997, nr. 42 pp 129
Lee, D., Kim S., Scharff M., Nielsen A., Meckelenburg M., Fuster-López L., Bratasz L., Andersen C., Numerical Modelling of Mechanical Degradation of Canvas Paintings under Desiccation, *Heritage Science*, Nr. 10 pp 1-13

[31] Roche A. Influence du type de chassis sur le vieillissement mecanique d'une peinture sur toile. *Studies in Conservation*, 1993, Vol. 38 nr.1, pp 17–24
Tiennot, M., Iannuzzi, D. & Hermens, E. Evolution of the viscoelastic properties of painting stratigraphies: a moisture weathering and nanoindentation approach. *Heritage Science*, 2021, Vol. 9, Nr. 77 *https://doi.org/10.1186/s40494-021-00552-x*

[32] Mecklenburg M., Tumosa C.S., Mechanical Behaviour of paintings subjected to changes in Temperature and Relative Humidity. In: Mecklenburg FM, editor. *Art in Transit: studies in the transport of paintings*, Washington DC: National Gallery of Art; 1991. p. 173-216.

[33] Schellmann N.C., Animal glues: a review of their key properties relevant to conservation, *Studies in Conservation*, Vol 52, 2007 Issue sup1: Reviews in Conservation 8 pp 55-66 *https://www.researchgate.net/publication/272311539_Animal_glues_a_review_of_their_key_properties_relevant_to_conservation*
Panzavolta S., Gelatin: a surprising material. Past, present and future applications. Water Based Adhesives in Conservation. Expert Meeting Program, Gallerie Nazionali Di Arte Antica, Roma, October 17-20 2022 (shortly to be available online)

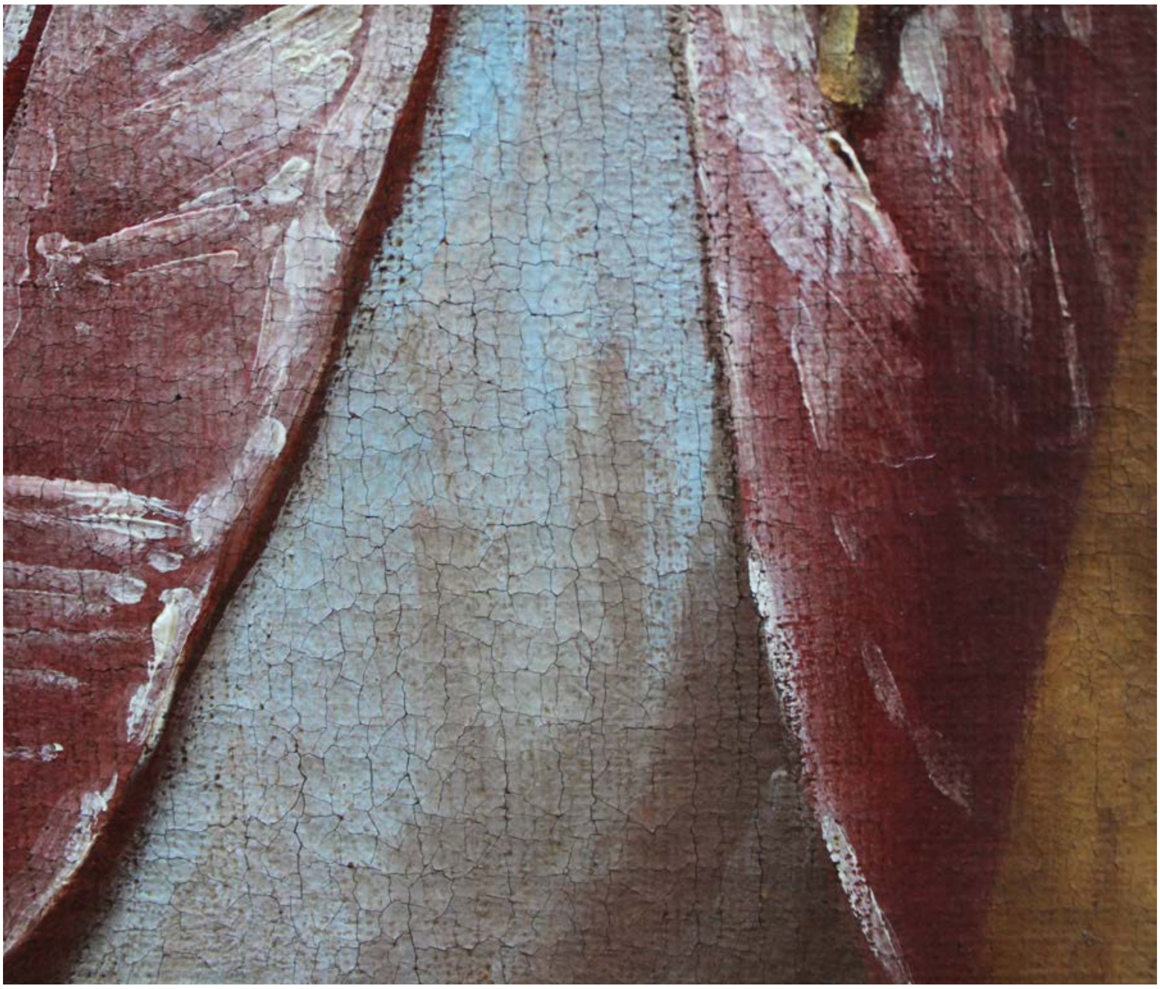
The reaction of the support of this painting (in this case a panel) has resulted in a cracking pattern in the ground and paint layers that run parallel with the wood grain. (W.J. van Smorenburg (1880-1918), *Grey Day*, oil on panel, 19.5 x 29.5 cm).

leads to high contraction forces, which the upper and lower strata can resist when young and flexible. However, even once the film is formed, it remains responsive to moisture uptake and cession. If maintained in stable, moderate relative humidity conditions, such internal forces relax. When subject to fluctuating environmental conditions, the mechanical properties of the animal glue content change effecting the glue's elasticity and resistance to creep, leading to significant damage to substrates. In dry conditions (below 30% RH), the glue will become brittle and internal cracks will form.
Note that once this phenomenon occurs, the formation of high stresses and transfer of such to the substrate is then reduced, until the dynamic cycle is re-instigated. In moist conditions, especially at elevated levels above 85% RH, the physical properties of the adhesive shift dramatically and all rigidity is lost as the animal glue returns to a gel state.[34] Subsequent high internal stresses will develop again when the moisture content drops and the film is reformed, which may lead to severe shrinkage in the film and forces being transferred to other adjacent layers. Cycling low to high RH conditions can cause a build-up of contraction mechanisms, with the material losing its ability to recover from elastic deformations.[35] This mechanical-physical cycle is typical of a painting exhibited in an uncontrolled environment, subjected to daily and seasonal cycles of relative humidity (*Diagram* 2).

Cracks, often called **age cracks**, have been noted in relatively young paint films applied on top of animal-glue bound ground layers. The morphology of those cracks, developed over time, can be used as a diagnostic tool in determining the originality, and confirming the support typology. Artists understood that the mechanical resistance of these animal-glue bound ground preparations was low, even if the mechanisms were not well understood in the past. Therefore, by the seventeenth century, artistic practice had adapted to

34 The solid to gel transition is the change from a solid state to a gel state. In this situation it refers to the dried animal glue returning to a gel state through the impregnation of the glue with moisture.

35 **Elastic deformation** refers to a temporary deformation of a material's shape that is self-reversing after removing the force or load. Elastic deformation alters the shape of a material upon the application of a force within its elastic limit. **Plastic deformation** is the permanent distortion that occurs when a material is subjected to tensile, compressive, bending, or torsion stresses that exceed its yield strength and cause it to elongate, compress, buckle, bend, or twist.



The craquelé pattern seen in this detail image of an oil on canvas painting is typical for aged painted objects on canvas. Detail of Mattheus Terwesten, *Aeneas saves his father from Troy*, 1701.

utilising more flexible, oil-bound ground layers, especially for paintings on the more responsive canvas supports.

Shifts in artistic practice also changed the desired colour of these ground layers over time, which also has impacted the mechanical-physical responses of ground layers. The pigment content of the ground layer will influence the formation of the matrix as the metal ions present in the mineral content interact and bond to fatty acids in the organic binding medium.[36] Early panel paintings required a white luminous surface to ensure full saturation and colour impact of (egg-)tempera bound paints and gilding, however the introduction of oil-binding media allowed artists to experiment with coloured grounds. Grounds rich in lead white respond differently to those rich in earth colours, leading to differential crack patterns and subsequent adhesion issues. Furthermore, the use of a base tone, so called **imprimatura layer**, to modify the colour of the ground, especially on Northern European panel paintings, reduced the need to apply thick ground layers.
Such panels often present less crack formation than those with thicker grounds. Panel paintings before the mid-sixteenth century constructed in Northern Europe show a different and reduced crack pattern compared to their southern equivalents from the same period.

Oil-ground panel paintings were also reported to be more resistant to cracking than those with thicker animal-glue grounds. However, seventeenth century practice in Northern Europe still employed a thin coating of animal glue direct to the panel support, and a thin layer of calcium carbonate bound in animal-glue ground before a coloured imprimatura layer. These panels do

[36] Casadio F., Keune K., Noble P., van Loon A., Hendriks E., Centeno S.A., Osmond G., (eds.) *Metal Soaps in Art*, Conservation and Research, 2019 (1st ed.) Springer

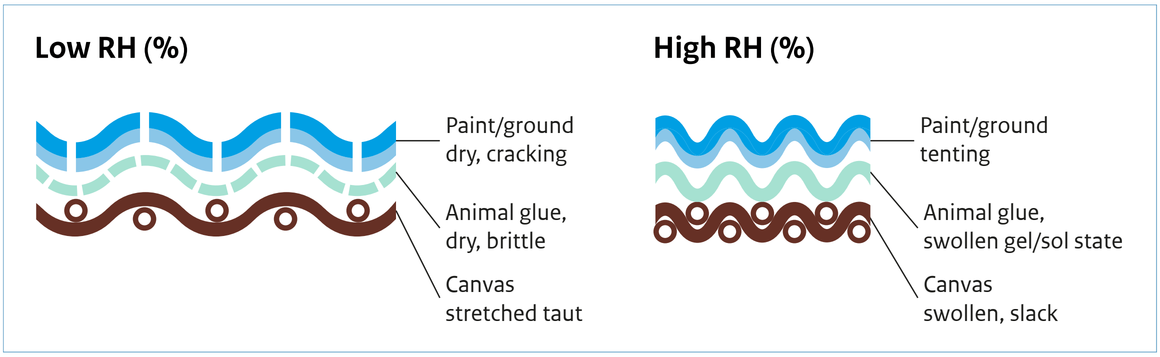
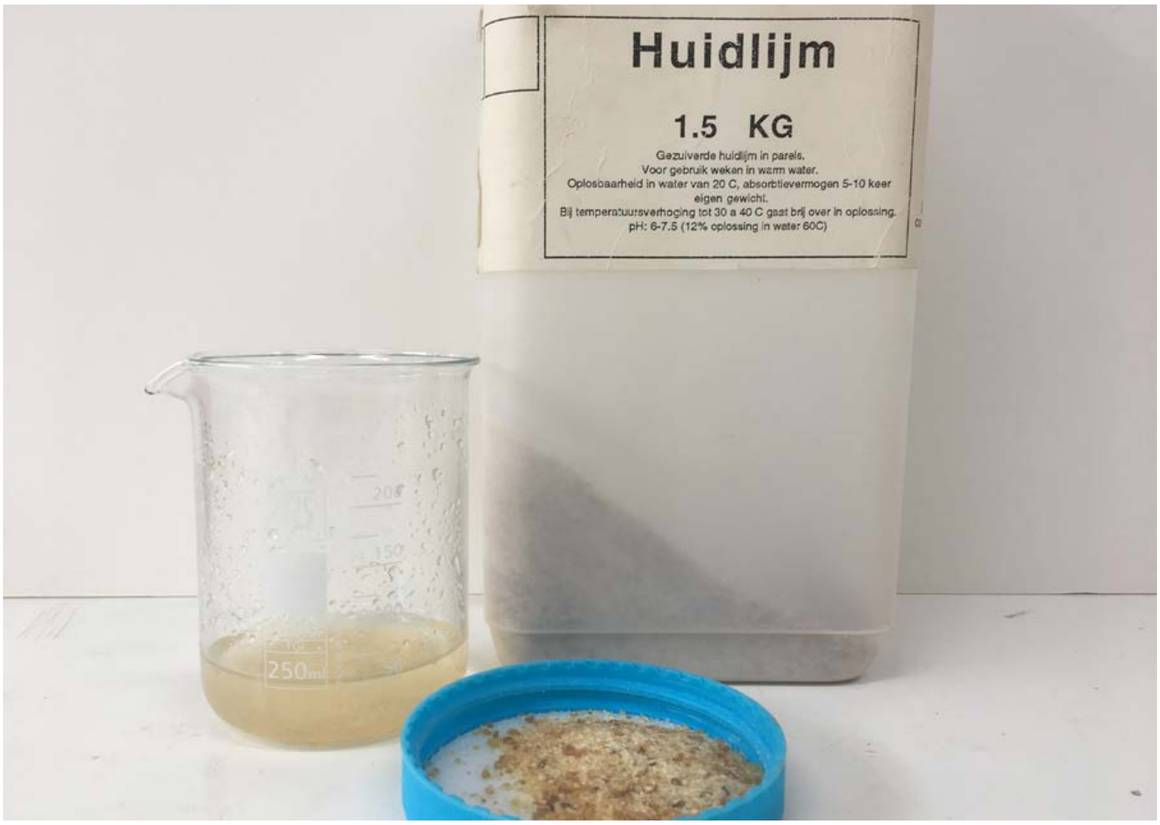


Diagram 2 showing the influence of relative humidity (RH) on animal glue.



Animal glue

present cracks that correspond to the wood grain of the panel support showing that the changing volumetric characteristics of the panel do play a role, especially when combined with the reduced resistance of the animal glue to these resulting forces.

By the seventeenth century, the preparation of canvas paintings had moved towards using (coloured) **oil-bound ground layers**. Studies have shown that some pigments used in the coloured ground increase the tendency of this layer to resist the volumetric change (swelling or shrinkage) of the underlying support layer and loss of resistance of the size layer. Canvas fibres swell in high relative humidity conditions, causing shrinkage of restrained textiles (textiles under tension).[37] At the same time the imbibed size layer loses its physical resistance as it also swells, and its stiffness is lost. As the moisture content of both the canvas and the glue is reduced, the canvas relaxes and expands, while internal stresses

[37] Hedley G., Relative Humidity and the Stress/Strain Response of Canvas Paintings: Uniaxial Measurements of Naturally Aged Samples, *Studies in Conservation*, Aug. 1988, Vol. 33, No. 3, pp 133-148
Michalski S., Paintings: their response to temperature, relative humidity, shock, and vibration. In: Mecklenburg FM, editor. *Art in Transit: studies in the transport of paintings*, Washington DC: National Gallery of Art; 1991. p. 223–48
https://www.academia.edu/741944/1991_Paintings_-_Their_Response_to_Temperature_Relative_Humidity_Shock_and_Vibration

Exposure to water, such as through a leakage or flooding, results in expansion and shrinkage of the canvas, with damage to the paint layer as a result. Here, the canvas has shrunk to smaller than its original size, leaving little room for the ground and paint layers, which has resulted in tenting of the paint. (Detail of Siep van den Berg, ***Composition*** 1, 1977, 62 x 75 cm, Acrylic on Canvas, Collection of the Cultural Heritage Agency of the Netherlands, Nr. BK25250) within the animal-glue will build up as it shrinks. Cracks in the upper lying ground and paint layers will ensue (*Diagram 3*). Once cracks occur, the mechanical stiffness of each layer changes as each layer is no longer a continuous layer. The interaction of each layer within the complex laminate structure will also change. Each layer's ability to resist forces and stresses will also alter. Further damage can result and is described below.

The paint layers and any coating applied over the ground layer will also play a role in the dynamic mechanical-physical behaviour of the painting. **Paints** combine organic and inorganic substances into a matrix that are applied on top of preparation layers. The selection of binding media by the artist is influenced by artistic practice, time period and geographical region. Early paints consist of gum or egg-tempera often applied to parchment, paper, canvas or wooden supports. The introduction of oil-paint revolutionised artistic practice allowing artists to model and paint more naturalistically. The porosity of the substrate will modify the consistency of the paint applied – the ground layer will absorb binding media from the applied layer, changing the rheology and flexibility of the dried paint film. The drying processes and internal stresses that build-up on film forming will influence the ability of the paint to adhere sufficiently to the substrate. Typically, paints are applied in much thinner layers than the underlying preparation, which also shifts their resistance to force and stress. It should be noted that the rheology and stiffness of different (colours) paints may result in different degrees of degradation over the whole surface of the painting. Crack patterns and delamination may be more prominent in certain pigments/paints than in others. **Drying cracks** may appear resulting from one layer drying at a different rate from that below. These cracks have a very different profile than those induced by the mechanical behaviour of the support and size layer. Interlaminar delamination may also occur if the adhesion between layers is compromised, either as a conscious artistic choice or due to inherent material degradation.

While the water-based paints remained bright on drying, the colour saturation of oil-paints improved with the application of a **varnish coating**. Thus, oil-paintings were consistently varnished and continue to be so until today. The trend is, however, defied by some well-known European artists in the late nineteenth and early twentieth centuries. The composition of such coatings also altered over time. Most varnish coatings consist of a tree-resin, often terpenoid in chemical composition, dissolved in ether (earlier) oil or (later) solvent. Combinations of resins and/or oils were frequently employed, and additives such as beeswax were included to decrease gloss. Varnish formulations simplified in the nineteenth and twentieth century, influenced by the introduction of chemical solvents. The mechanical-physical properties of tempera and oil paint tend to be more flexible and resilient to cracking than the underlying ground layers. Varnish layers, on the other hand, especially solvent-based varnishes, dry to rigid, brittle layers. These layers, on aging, can crack and even shatter, applying tension to and transferring forces into the underlying paint inducing further cracking. Additionally, the latest studies show that these layers are not impervious to water-uptake.[38] However, their moisture absorbency capacity and their dimensional response to moisture are not to the same degree as the more reactive layers lower in the complex, three-dimensional structure.

As discussed, the interaction of these layered, complex, three-dimensional structures can lead to cracking, scission or splitting causing powdering, delamination or flaking at the interface between layers and manifest differently over the surface of a painting according to colour or position. For instance, light-coloured paints containing lead white may not show pronounced craquelure, other colours may crack considerably. Therefore, the materials' mechanical-physical properties and degradation patterns are essential to understand when designing a protocol for treatments such as consolidation. Understanding the causes of degradation will allow the conservator to make better choices in material selection for remedying their physical manifestations and extend the scope and functionality of their life performance.

[38] Baij, L., Hermans, J., Ormsby, B. *et al.* A review of solvent action on oil paint. *Heritage Science*, 2020, Vol. 8, Nr. 43, *https://doi.org/10.1186/s40494-020-00388-x*

Drying cracks may appear as a result from one layer drying at a different rate from that below, which may derive from ignoring the 'fat over lean' rule. Detail image of T. De Bock, *Landscape with sunset, view of a group of trees at the waters' edge*, ca. 1875-1900, oil on canvas, 32 x 45 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. B528.

Detail image of J.A. Heesterman, *Mountain landscape with river*, 1871, oil on panel, 15 x 59.5 cm. The differing tensions in the varnish, paint, ground and panel have resulted in tenting and flaking of the paint and ground layers, resulting in loss.

Damage patterns to complex laminate structures

The damage type can be characterised by two inherent factors: **adhesion** and **cohesion**. All factors are influenced by the materials chemical, physical and mechanical properties. Determining whether a painting's structure is presenting damage resulting in a loss of adhesion or cohesion is the first aspect to assess when observing paint layers requiring treatment.

Adhesion issues are distortions or damage at the interface **between** layers of paint, ground and support, and result in phenomena such as flaking, blistering, lifting, tenting and delaminating paint. **Cohesion** issues relate to issues **within** a singular layer, such as ground or paint layer, and result in phenomena such as crumbling, powdering and cracking (*Diagram 4*). Once cracks in the upper decorative layers have set in, further mechanical processes may evolve in other damage patterns.
The reduction in volume of the support, as a reaction to shrinkage caused by absorption of moisture, may cause the edges of the islands of paint/ground to raise up causing **cupping**.[39] Cupping of these stiffer layers occurs due to a redistribution of tension from the lower strata to the upper layers. If compression sets in, due to further shrinkage of the support, the cupped ground and paint layers can delaminate and detach from the support. This phenomenon is often referred to as **flaking**.
Paint and ground loss can occur. This physical manifestation of mechanical degradation processes evolves over time as the support and size layers respond to fluctuations in relative humidity.

Often these phenomena do not exist in isolation, so cracking, delaminating and flaking paint and ground layers may be observed detaching from a support, or crumbling and powdery paint phenomena may be seen in the same area of paint. Adhesive or cohesive damage to paint and ground layers can be found either locally (in a certain section or area of a painting, or a particular colour) or over an entire painting.

In painting conservation, the treatment of this phenomena caused by inherent vice is called **consolidation**. Consolidation refers to the stabilisation and reattachment of paint and/or ground layers to the underlying substrate. The action aims to restore the cohesion and/or adhesion of the layers that have lost the ability to stay together. Consolidation can occur on a local level to deal with isolated areas of flaking, lifting, crumbling or delaminating paint. A fluid adhesive, which cures to a film, will be introduced to areas presenting damage from the verso (the painted side).

[39] Andersen C., Mikalski S., Mecklenburg M., Water Based Adhesives in Structural Painting Conservation, Expert Meeting Program, Gallerie Nazionali Di Arte Antica Roma, October 17-20 2022
Mecklenburg M., Tumosa C.S., Mechanical Behaviour of paintings subjected to changes in Temperature and Relative Humidity. In: Mecklenburg FM, editor. *Art in Transit: studies in the transport of paintings*, Washington DC: National Gallery of Art; 1991. p. 173-216.

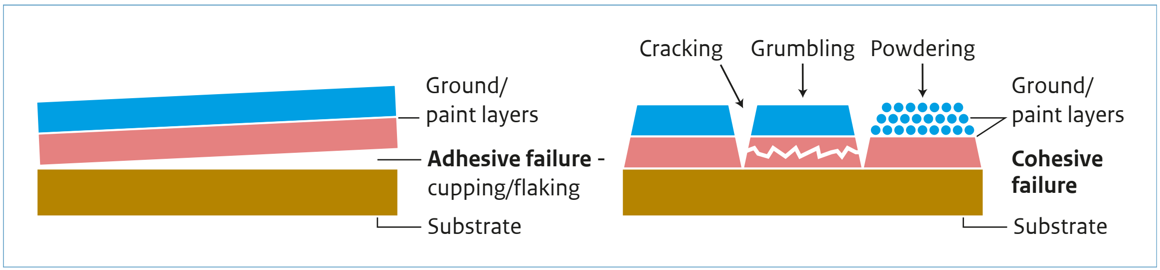


Diagram 4 showing some of the types of adhesive and cohesive failure within the paint structure.

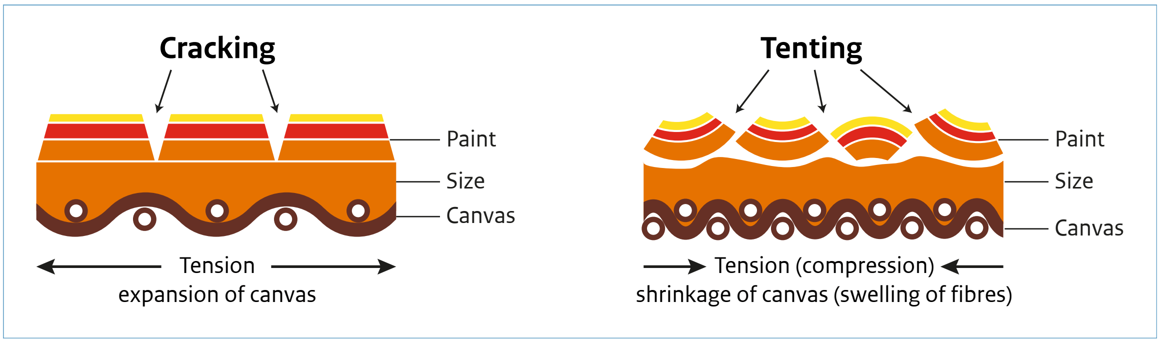


Diagram 3 showing the expansion and shrinkage of canvas as a reaction to humidity conditions, and the resulting effects on paint and ground layers.

Detail of Siep van den Berg, *Composition red-blue-yellow-red barricade*, 1963, oil and casein paint on canvas, 90 x 150 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. SZ37191. Damage to the paint was restricted to the blue paint, where it was found to be crumbling, powdering and flaking.

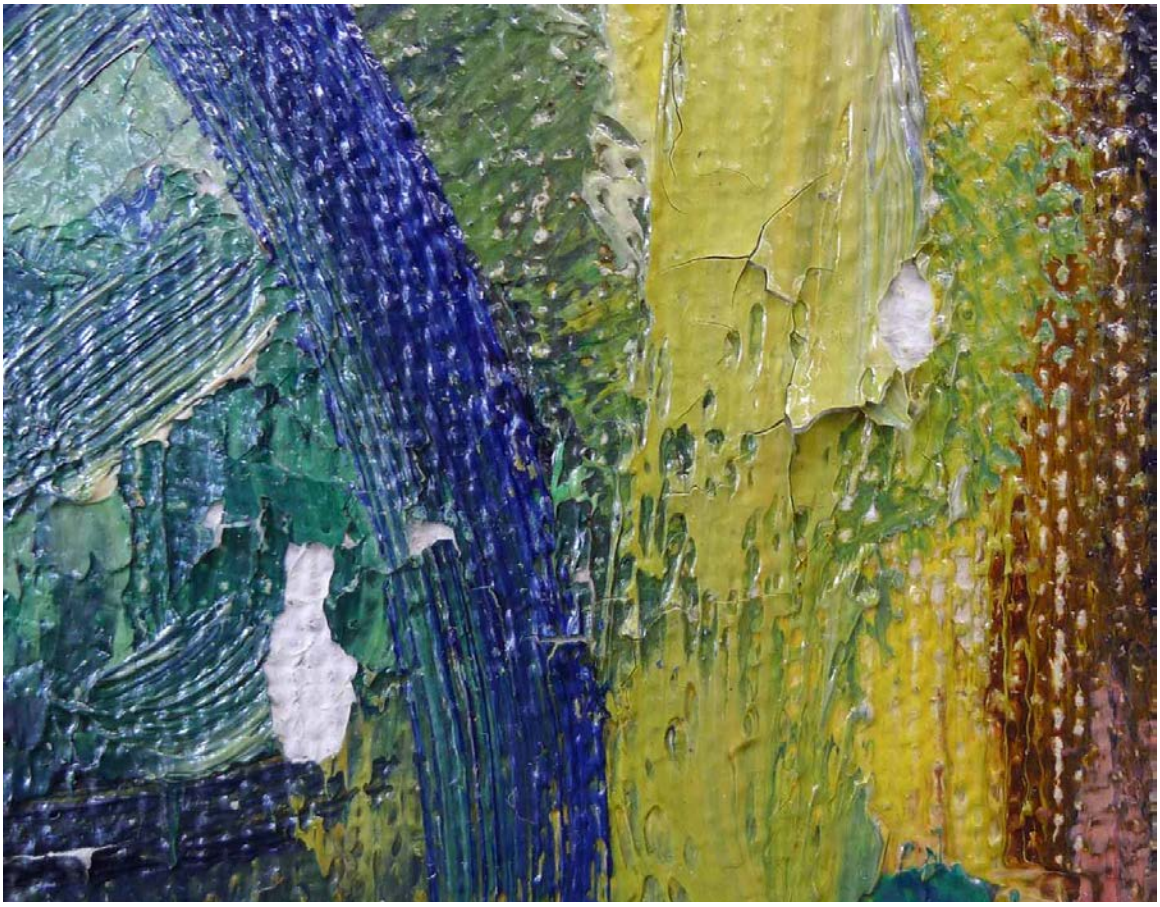
However, paintings exhibiting considerable flaking frequently require more extensive consolidation and additional structural treatments, such as lining.[40] If the flaking phenomenon is more predominant, then a consolidant can be introduced from the recto (the reverse) of the original canvas. Typically, in the past, linings were designed to incorporate, in one single treatment, consolidation of flaking paint, mitigation of surface topography deformations, and application of an additional lining support. More recent lining systems do separate out these actions and the lining canvas is applied to the pre-treated canvas (see the brochure on: *The Structural Conservation of Canvases and Panels*).

Applying an adhesive to one local area may exacerbate issues in another area. The introduction of an adhesive may change the response rate of the impregnated area to external factors and conditions. Differential stresses and/or swelling/shrinkage patterns may exasperate problems in adjacent areas. Global treatments should be considered in terms of the mechanical stresses that may be induced to the three-dimensional paint, ground and canvas structure during treatment. Adhesives are introduced in fluid form to the porous laminate structure and cannot be entirely removed. They will flow through pathways that may not be visible or desired beyond the area that is presenting damage (*Diagram* 5). They may change the appearance of the paint or ground through saturation, and they should certainly not interfere with future treatments that may not be yet determined. Consolidation treatments may, therefore, differ according to the type of painting that is being treated and the support which was selected by the artist.

It is, therefore, important to understand the different types of degradation and their potential underlying causes to determine subsequent treatment steps. Below are some of the common causes of adhesion and cohesion issues in paint and ground layers.[41]

[40] Lining is often used as a last resort when the support does not have the strength to hold the (re-)adhered paint and ground layers. However, newer methods of lining propose that consolidation is carried out as a separate independent step prior to the attachment of a secondary canvas. See Brochure on: *The Structural Conservation of Canvases and Panels*.

[41] Von der Goltz, M., Birkenbeul, I., Horovitz, I., Blewett, M., Dolgikh I., Consolidation of Flaking paint and ground' in: Hill Stoner, J., Rushfield, R., (eds.) *The Conservation of Easel Paintings*, 2021 (2nd ed.) pp 389-405



Detail image of T Roovers, *Flowers*, 1947, oil on canvas, 91 x 74 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. K1324. Here the paint is seen to be cracking and delaminating, resulting in loss of paint.

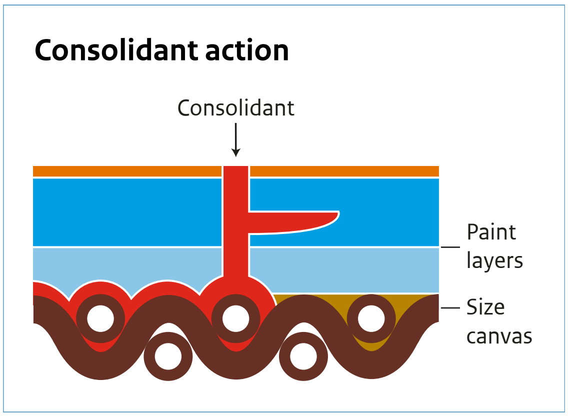


Diagram 5 showing the action of a fluid adhesive consolidant flowing into the visible and invisible pathways of the laminate structure.

Causes of paint degradation

Inherent vice refers to the inborn degradation phenomena that result from the choice of materials and techniques. These may cause instability of the individual layers or the laminate structure. Paintings that are created with unstable, poor quality or improperly mixed materials, or with poor painting techniques (such as ignoring the 'fat over lean' rule) will be susceptible to adhesion and cohesion issues.[42] Underbound media will result in powdering and crumbling paint; medium-rich paint can shrink, embrittle, cup or flake, with overlying layers adhering poorly to them. Improperly mixed paints (pigment and binder) or mixtures of oil and acrylic paint will also lead to adhesion and cohesion issues. Paints made according to old master recipes tend to exhibit less evidence of inherent vice than newly formulated paints. Experimental or self-formulated paints may be more prone to these degradation phenomena. It should be noted that the rheology and stiffness of different (colours) paints may result in different degrees of degradation over the whole surface of the painting. Crack patterns and delamination may be more prominent in certain pigments/paints than in others (see *Diagram 6*).

Environmental factors such as fluctuations in humidity and temperature can also cause adhesion and cohesion issues. Abrupt or significant changes in relative humidity (RH) can cause paint and ground layers to swell and expand or shrink and contract. Layers may react in opposing directions causing shearing or cleavage. As mentioned, cracks can occur when these forces are countered by shrinkage or expansion of the support. Delamination and flaking result when the ground or paint layers are compressed and no longer 'fit' into the space allotted. Mechanical-physical loads and stresses can build up at the interface between the ground and support, resulting in tenting, flaking, and delaminating paint.[43] This can also present as blind cleavage on panel paintings. Excessive exposure to intense heat, such as exposure to direct sunlight, from irons used in previous restoration, or from fire, can result in the disintegration and flaking, cupping and blistering of paint.

Mechanical damages can result from accidents, poor handling, and inadequate storage as well as from normal use and handling. Mechanical damage can result from punctures, tears, or indentations in the canvas, and/or chips, dents, cracks, and scratches in the paint layers. Damage from impact or handling can cause the paint to lift, flake, cup or detach. Often the impact does not have immediate consequences and the damage only becomes visible many years in the future, such as spiral craquelure which result from an impact, or over-tensioning the

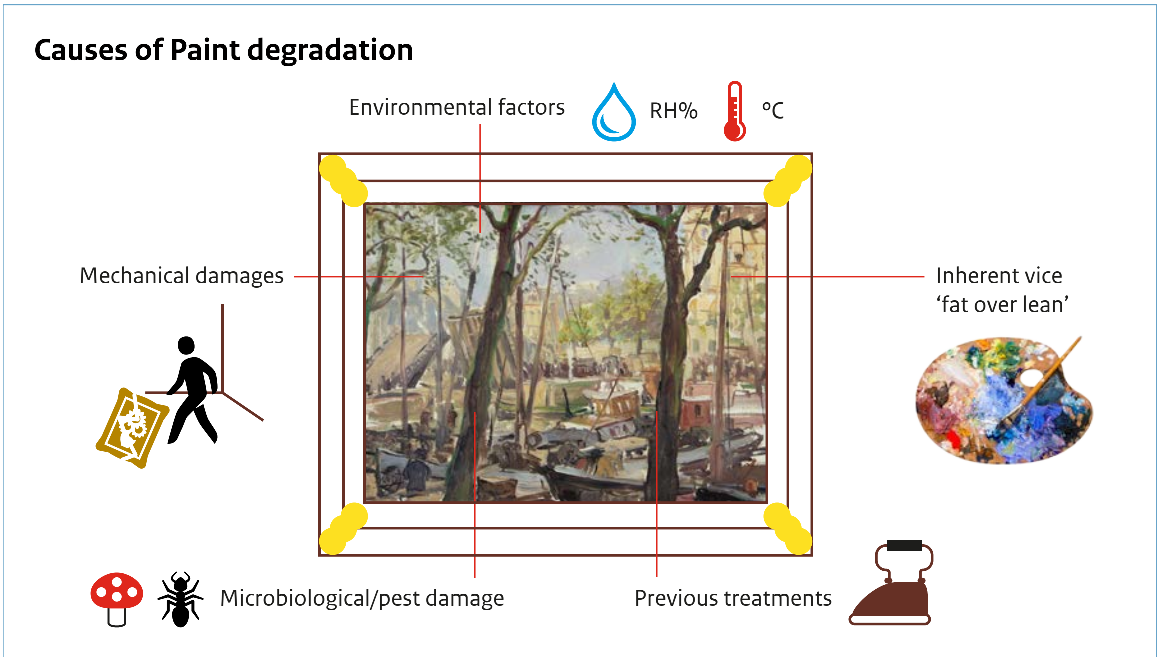
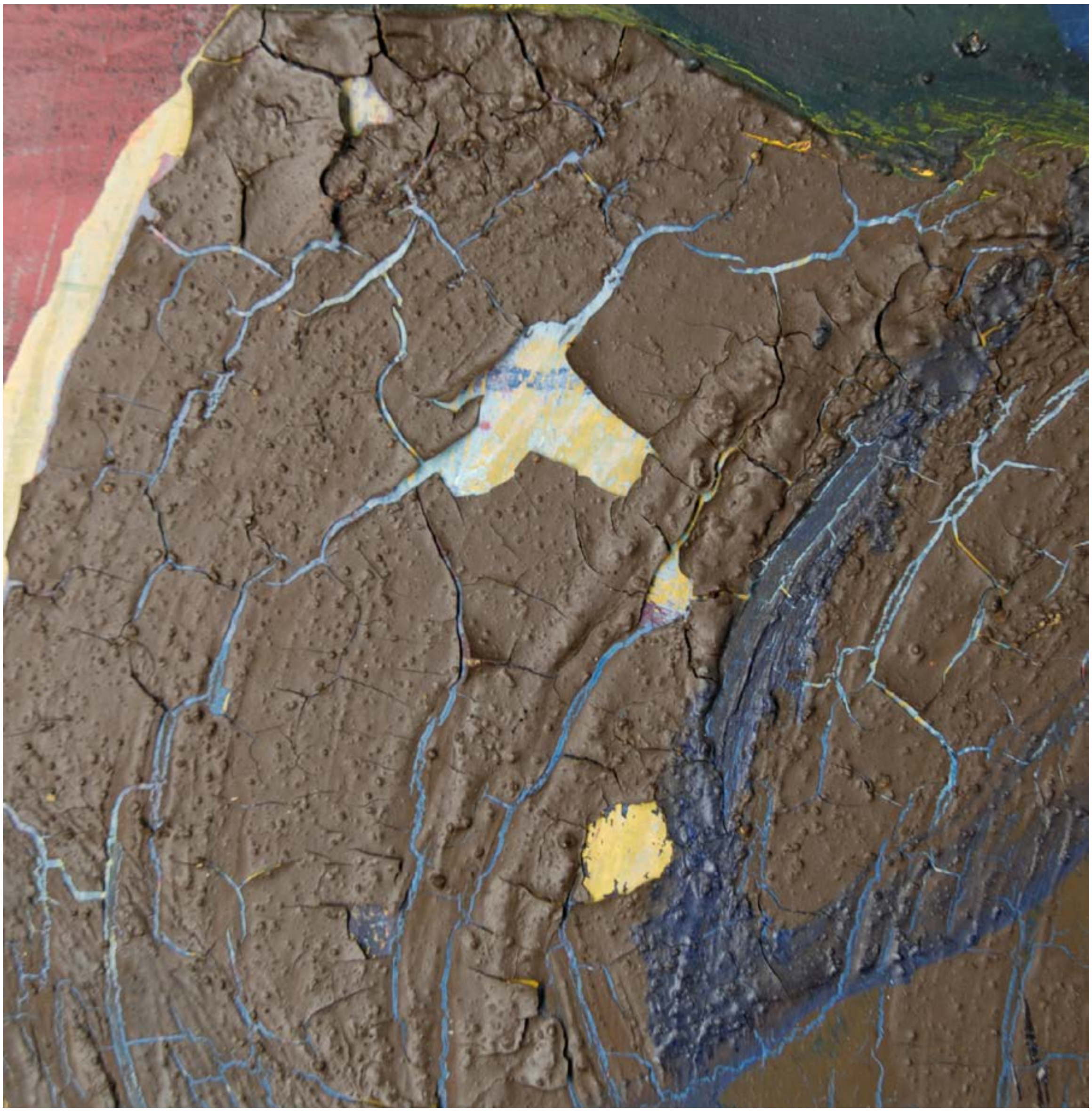


Diagram 6 illustrating the various causes of paint degradation.

[42] Bucklow S., 2020, pp 285-290

[43] In the case of canvas supports, the shrinkage occurs when swollen, enlarged weft yarns cause the crimped warp yarns of the canvas to become accentuated and drawn more closely together, which in turn forces the paint upward.

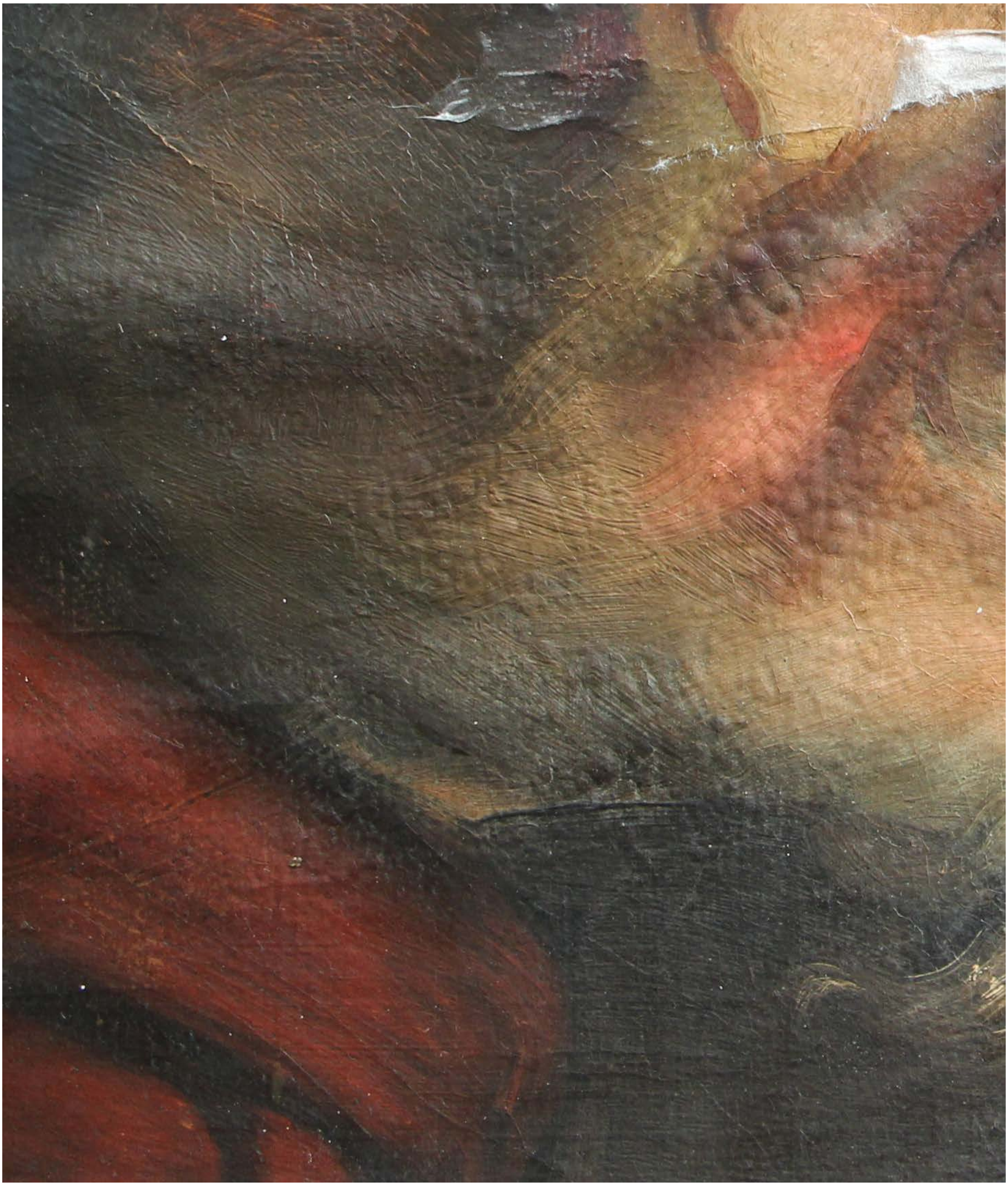


Inherent vice: Detail image of D. Wechgelaar, *Ebb Current*, 1966, gouache and oil on canvas, 122 x 121.5 cm, Collection of the Cultural Heritage Agency of the Netherlands, Nr. SZ33000. The choice of materials and technique has led to adhesion and cohesion issues.

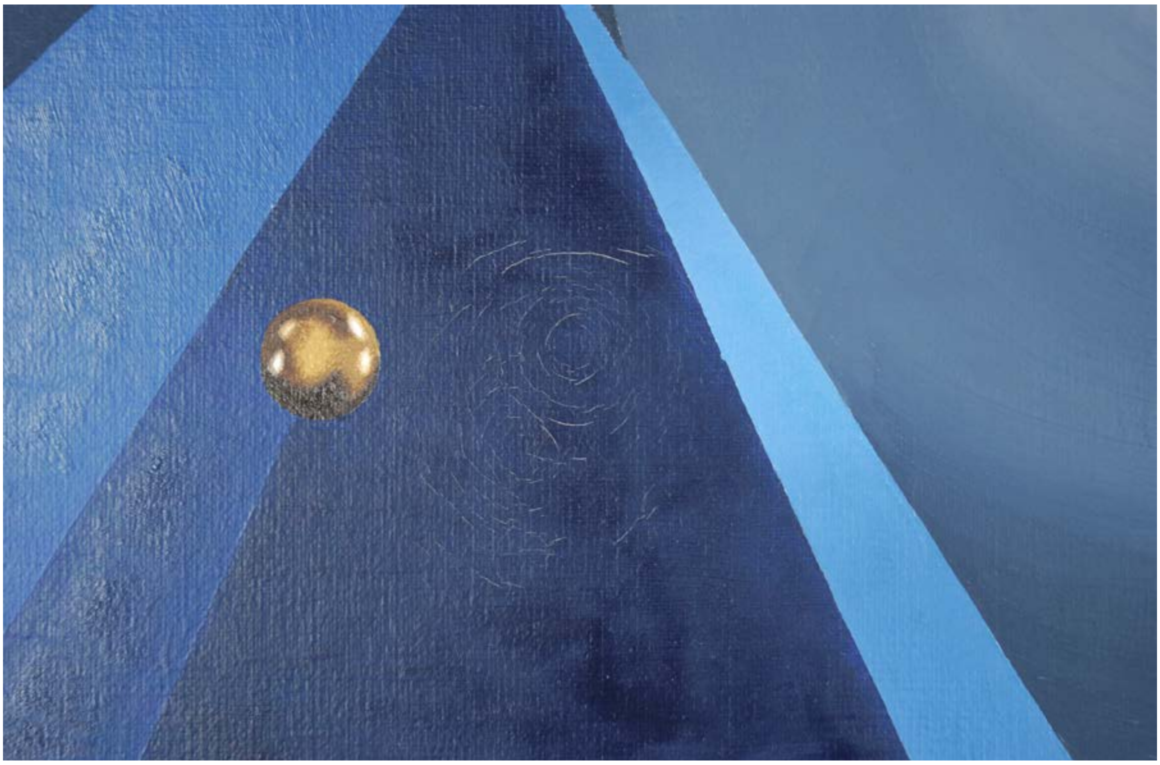
corners of a canvas painting during mounting to the secondary support. Vibration during transit can further loosen layers that are already weakened prior to movement of the artwork. In fact, paintings exhibiting flaking issues should not be transported and should not be loaned.

Microbiological or pest damage can occur as the result of a poor storage or display environment in which a painting is kept. Poor storage in damp environments (or in damp microclimates) or unforeseen disasters such as flooding, water leakages or sprinkler systems (as the result of fire) will result in mould growth if the painting remains damp for long periods of time. Paintings exposed to an environment with levels of RH as low as 70% can grow mould within 24 to 48 hours.[44] Mould and other biological activity can result in the increased powdering and sensitivity of the paint due to the weakening of the binder. Insects may feed on binding media resulting in the disintegration of the paint layers (powdering/ crumbling), or the supports (cellulosic or proteinaceous

[44] Erhardt, D, Tumosa, C., Mecklenburg, M.F., Applying science to the question of museum climate, in: Padfield T., Borchersen, K., (eds.) *Museum Microclimates*, 2007, Copenhagen: National Museum of Denmark *http://eprints.sparaochbevara.se/27/2/erhardt.pdf*



Environmental factors: Excessive exposure to intense heat has caused the blistering of this paint.



Mechanical Damage: Detail image of H. van Es, *Hanging Pyramids*, ca. 1981, oil/acrylic on canvas, 100 x 85 cm, Collection of the Cultural Heritage Agency of the Netherlands, Nr. DV8986. Mechanical damage, such as impact from an accident can result in spiral cracking.

material), undermining the paint layers and causing them to collapse.[45]

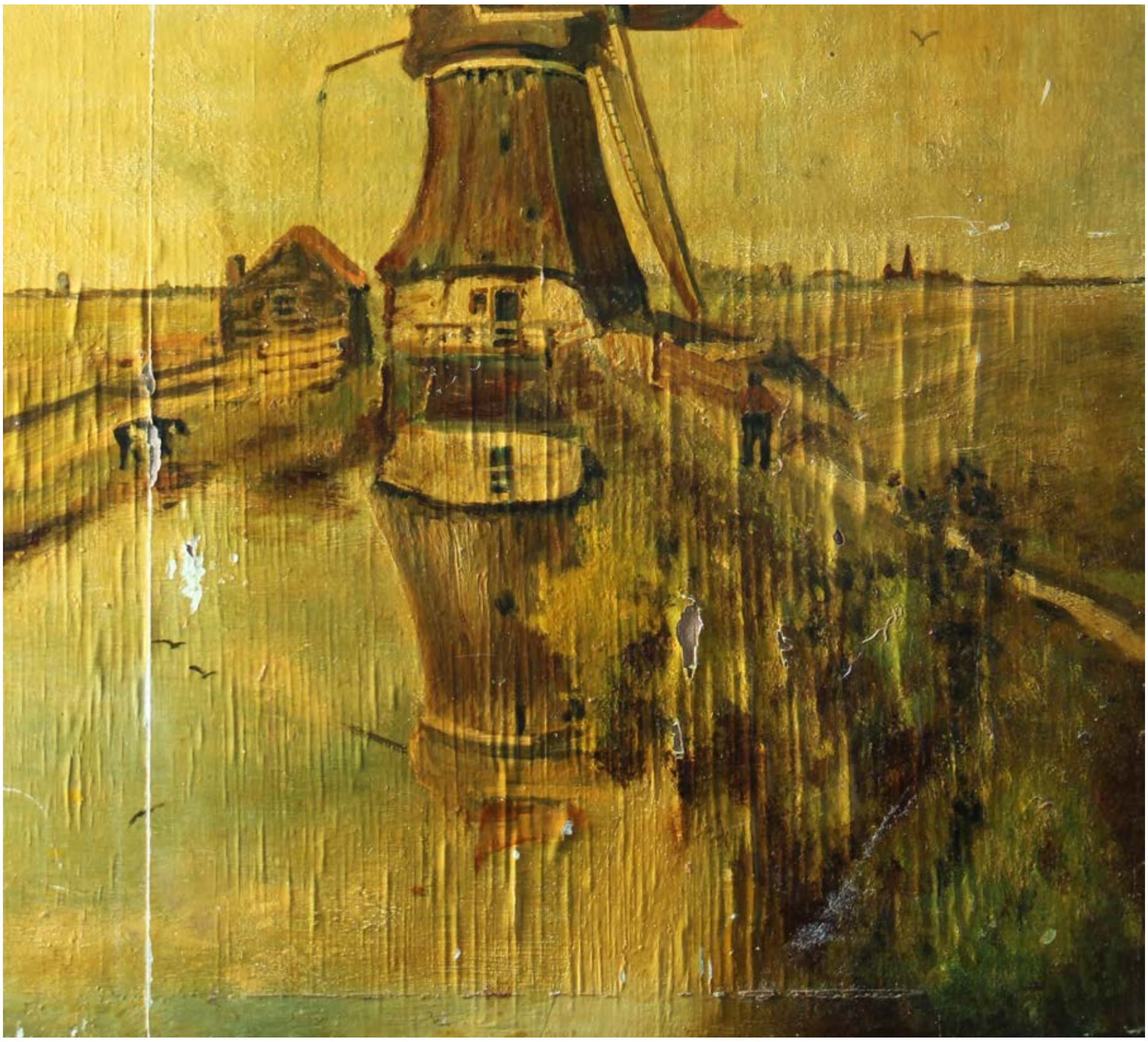
Previous treatments that have been poorly executed or have degraded over time can also result in damage to the paint and ground layers, such as exposure to heat from irons used in previous structural treatments. Treatments that did not adequately address the adhesion or cohesion issues, or the incorrect choice of materials to address an issue will lead to further damage to the paint film and ground layers. If the strength and rigidity of a previously introduced consolidant exceeds that of the surrounding paint film, new patterns of deterioration such as cupping, flaking and cracking can develop at the site of the repair during the painting's natural movements in response to its environment. Weak, inappropriate adhesives will lead to the need for re-treatment. Wax(-resin) adhesives or glues containing wetting agents may cause layers to slip rather than stick.[46]

The application of wax (or wax-resin), in fluid form, will alter the saturation of the ground and paint, changing the colour and appreciation of the artwork. This may also be the case when applying modern wax-resin mixtures such as Lascaux Adhesive Wax or BEVA 371TM. Consolidating modern and contemporary paintings using media can also be challenging as fluid consolidants can form tidelines when curing.

[45] Petersen, K., Klocke J., Understanding the deterioration of paintings by microorganisms and insects, in: Hill Stoner, J., Rushfield, R., (eds.) *The Conservation of Easel Paintings*, 2021 (2nd ed.) pp 710-730

[46] Von der Goltz, M., Birkenbeul, I., Horovitz, I., Blewett, M., Dolgikh I., Consolidation of Flaking paint and ground' in: Hill Stoner, J., Rushfield, R., (eds.) *The Conservation of Easel Paintings*, 2021 (2nd ed.) pp 389-405

Microbiological growth: Detail image of J. van Malderen, *River View*, oil on canvas, 30 x 40 cm. Mould and other biological activity can occur when the painting remains exposed to damp for long periods of time. Here foxing is a result of microbiological activity.



Detail image of: G. Langkof, *Windmill by a river*, oil on panel, 30 x 20 cm. Various mechanical, physical and chemical forces between and within the various paint, ground, varnish layers and support have resulted in severe tenting and delaminating of the paint and ground layers.

Paint Degradation Phenomena

Identifying and classifying the damage presented by the painting into the categories below will allow the conservator to make critical choices when selecting the appropriate adhesive for the task in hand. The properties of the adhesive and the manner in which it will be applied will also need to be considered. Additionally, the conservator will require knowledge of tools and methodologies to prepare the area or indeed the whole painting prior to applying consolidants.

Damage Atlas

The following **damage atlas** will help in identifying the type of degradation and the type of treatment that is required:

Blistering: Local separation of a top layer from a lower layer without a break (crack) in the top layer often with a stretching (swelling) of the top layer and often a void between the layers due to the development of a gas resulting from overheating. Blistering frequently results from thermal damage or the application of a substance. Blisters result in extremely fragile air pockets that can occur between paint layers after the painting is exposed to excessive heat. The adhesive chosen to deal with this type of damage needs to be able to flow below the blister and fill the void between the layers.

Cleavage: Lateral separation between layers, as between a paint or varnish film or other film layers, or between a film layer and its support where the paint layer has partially raised itself off the underlayer/support, but is still partially attached to the support. This may happen at the interface between two layers, especially if the mechanical-physical or chemical properties of the individual layers differ. Water damage may often lead to ground and paint cleaving away from the support.

Cracking: A break in a surface resulting in a visible separation of one part from another, extending through one or more layers. Cracking is caused by the expansion and contraction of the layers accompanied by a loss in elasticity. It can be the result of environmental fluctuations, vibrations, internal or external stresses or flaws in the surface. Cracking can be subdivided into: hairline cracks, microcracks (crazing), star cracks, aging

Cracking paint. Detail image of: J. Veneman, *Shoe, Kettle, Pipe and Coffee Grinder*, 1983, oil on canvas, 194 x 190 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. DV15276.

Feather and spiral cracks. Detail image of: J. Wittenberg, *Pollard willow in the snow*, oil on canvas, 65 x 51 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. K260.

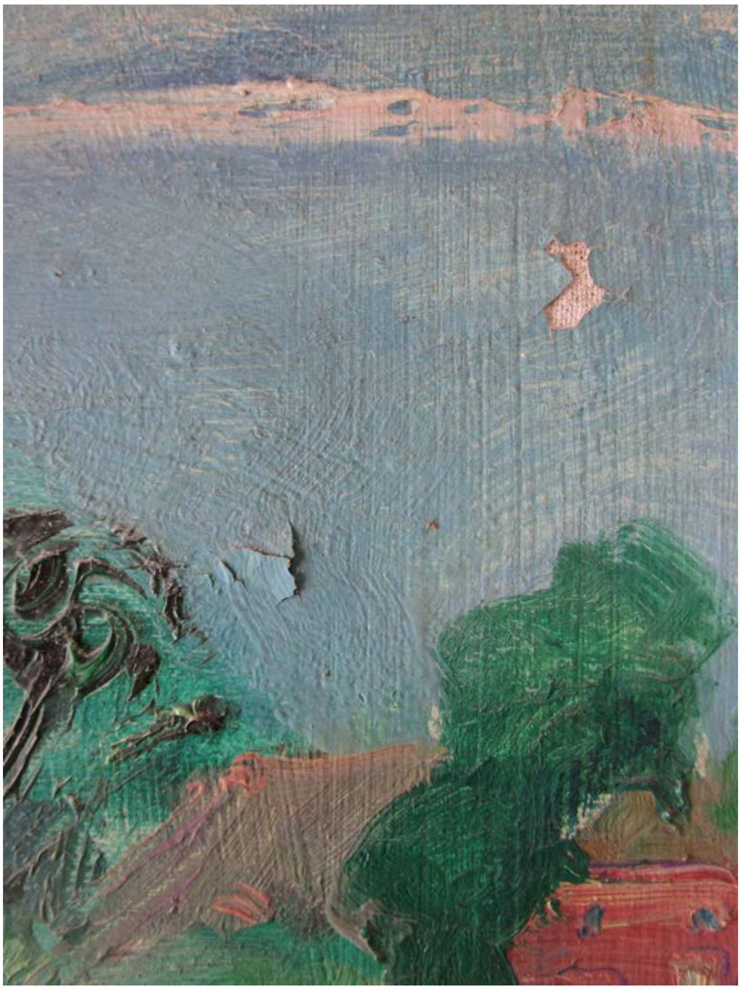
cracks, radial or spiral cracks, craquelures, traction cracks, stretcher bar cracks, stress cracks or feather cracks. While cracking can be reduced by manipulating and controlling the environmental conditions, and by applying backing boards when the painting is young, it is inevitable. Ensuring that cracking does not develop into cupping and delamination is essential. A network of cracks in a paint layer caused by aging, technical errors or by differential movement of the layers and the substrate is known as ***Craquelure***. It is inevitable that an aged painting shows a subtle crack pattern. Different supports and regional making processes produce different crack patterns; thus, the type of crack pattern can be used to identify the type of support, size layer, ground application and painting technique. Crack patterns may not be uniform over the whole surface. Cracking can be mitigated but not avoided. It is rarely necessary to consolidate a cracked painting, unless cupping occurs.

Crumbling: A friable (paint) layer that has broken down into small pieces no more than a few millimetres in size and detached from the support. Disintegration as a result of chemical, physical or biological deterioration causing the gradual dissolution of binding medium. In these cases, the consolidant is required to replenish or substitute the original binding medium and will need to be a fluid, non-viscous material. It is vital that the consolidant flows throughout the full paint strata.

Cupping: Formation of a concavity or cuplike hollow in a paint layer. Often found in aged paint, which is cracked, where the edges curl upward at the cracks to create cup-like formations. Here the paint layers are stiffer than the underlying support and carry the planar tensionin the horizontal direction. The deformations in the surface are often transposed to the reverse of the canvas support and can be seen when viewed in raking light from the reverse. Severe cupping, if left unchecked, can lead to compression stresses building up at the edges, especially if the canvas support has 'shrunk' minutely. Mitigation may require gentle humidification and tensioning of the primary support, followed by consolidation if any lifting has occurred. Paintings that have cupped paint that have been previously cleaned may have varnish material trapped between the cups. This (non-original) material may impede consolidation and can be removed by using a varnish removal system that absorbs the varnish without significant mechanical action. (see the brochure on *Varnish Removal* for more information). Canvas paintings that present this problem often have a negative pattern of the craquelure on the recto of the canvas.

Delaminating: The process by which various (paint) layers (partially) separate from each other and/or the support underneath. Again, here an adhesive must be able to flow between the two delaminating layers and set into a film binding both parts together. This phenomenon may be the result of internal shear forces present in the lower layers of the painting. Grounds containing zinc white are especially prone to this type of damage.

Flaking: The separation of paint into thin, flattened pieces or layers due to a combination of loss of adhesion and cracking. In this case, humidifying the support until a relaxation point is reached, subsequently applying gentle tension and then 'setting' the support in a 'new' slightly elongated position by drying under tension, may provide enough space for the cupped paint to lay down flat. Any lifting at the edges of the cup can be re-adhered by introducing a fluid adhesive compatible with the size layer or regenerating the size layer.



Cupping and delaminating paint. Detail image of: W. Hoving, *Landscape with field*, oil on canvas, 82 x 93 cm. Private collection.

A cupping paint flake. Detail image of: P. Celie (T. van de Bult), *Composition A*, oil on canvas, 197 x 140 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. SZ44005.

Lifting: Partial rising of a topcoat such as a paint or varnish layer, due to a break in adhesion from the underlayer. Similarly to delaminating paint, the adhesive used to mitigate this situation must be able to flow to beneath the lifting paint.

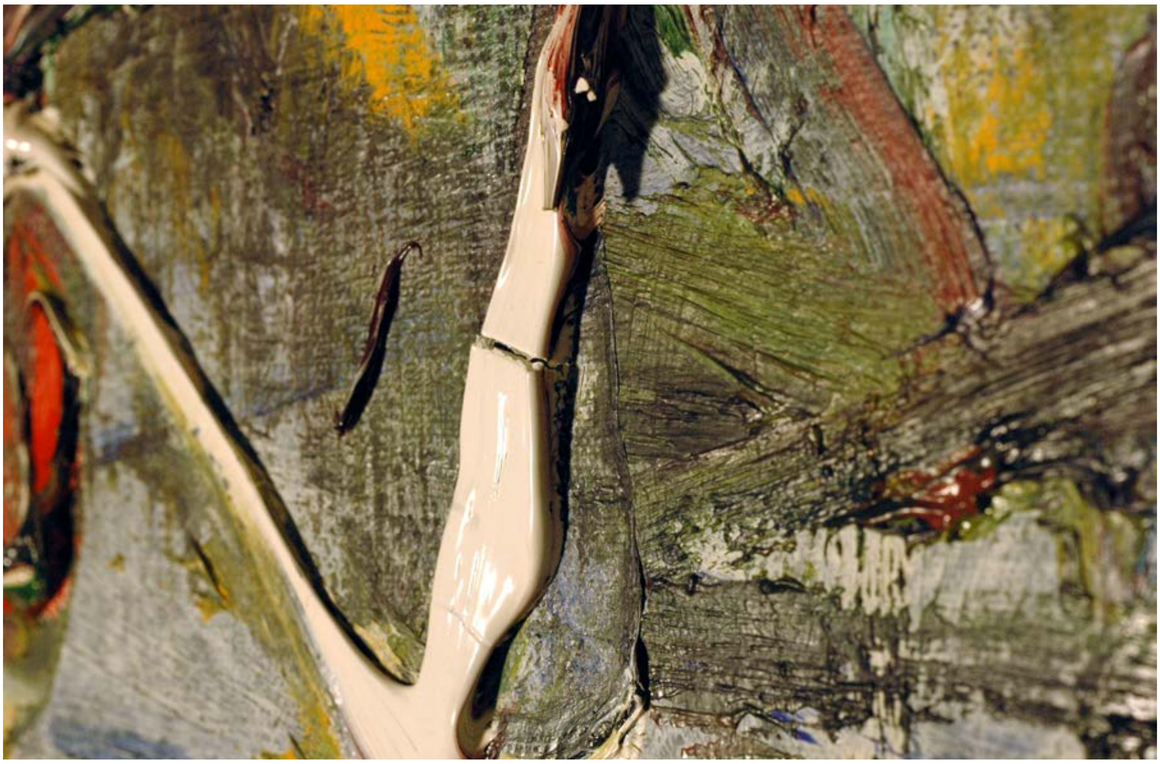
Powdering/Chalking: A dry, matte surface appearance where the paint often also becomes whiter and lighter. It generally starts on the surface and alters either only the surface or up to a few micrometres deep. The visual effect of chalking or powdering is due to the scattering of light of the surface paint film caused by the breakdown of binding medium causing a loss of cohesion and the generation of very fine particles on the surface. This may affect only one colour, or only one area of a painting. This phenomenon often happens if a component of the paint migrates out of the paint matrix.

Tenting: Vertical displacement between layers, generally following a pattern of cracks, resulting in converging sides that resemble a tent. This phenomenon often happens with panel paintings, especially when the wooden support has lost moisture content and shrunk. It will also occur on canvases that have been lined, and where the canvas has shrunk in the process.[47] It is extremely difficult to remedy if there is insufficient space for the raised paint to lay down flat. Too much pressure applied when the paint is brittle will cause shattering and further loss.

The identification of the particular damage phenomenon or phenomena described above that is present on the painting will allow the conservator to critically select the adhesive to be used as a consolidant and a suitable application method.

Tenting paint. Detail image of: Vilmos Huszár, *Old Woman*, 1907, 80 x 56 cm, homemade paint on canvas. Collection of the Cultural Heritage Agency of the Netherlands, Nr. SZ15713

[47] Andersen, Cecil. (2013). Lined canvas paintings, Mechanical properties and structural response to fluctuating relative humidity, exemplified by the collection of Danish Golden Age paintings at Statens Museum for Kunst (SMK).



Cracked and lifting impasto. Detail image of: C. Bohemen, *Piacenza*, 1984, oil on canvas, 140 x 200 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. K85082.

Powdering or chalking paint. When handling the painting, the powdered paint immediately transferred to the gloves. Detail image of: Siep van den Berg, *Composition red-blue-yellow-red barricade*, 1963, oil and casein paint on canvas, 90 x 150 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. SZ37191.

Crumbling paint. Detail image of: Vilmos Huszár, *Old Woman*, 1907, 80 x 56 cm, homemade paint on canvas. Collection of the Cultural Heritage Agency of the Netherlands, Nr. SZ15713

Concurrent Condition Issues

On occasion, the painting may have additional condition issues that may need to be addressed prior to, or concurrently with consolidation treatment. For example, a canvas with a tear and resulting deformation may require flattening and mending prior or concurrently to consolidation. Where local damage to the underlying support is present, such as a deformation in the canvas from impact damage, this should be treated prior to the paint and ground layers when appropriate. Alternatively, the flattening, mending and consolidation of the damages may be done alternately in a stepwise fashion, as paint affixed to a deformed surface will result in improper alignment of the paint flakes, which in turn may hinder adequate room for flattening and mending.

In many cases, the support must first be stabilised and treated by humidification and flattened using tensioning systems, and/or mended prior to the consolidation of the paint layer. It is usually better to treat each problem individually to ensure the solution is appropriate and minimise invasive actions, however it is sometimes also necessary to treat the support and the paint layer simultaneously. Temporary stabilisation methods may be appropriate to flatten deformations surrounding the area presenting flaking paint in order that a consolidant can be safely introduced.

Another example where concurrent issues must be addressed, is the presence of surface dirt in an area where flaking or other adhesion or cohesion issues occur. It is necessary to assess if the surface dirt can be safely removed without causing movement or loss to the detached, loose or powdering paint and ground layers. The application of a consolidant without prior removal of surface dirt may result in dirt becoming trapped in the cracks between or under the paint flakes by the consolidant, permanently altering the appearance of the artwork. Where the paint has cohesive failure, the consolidation of powdering paint without concurrent dirt removal will permanently affix the surface dirt to, and in, the paint.[48]

The canvas support must often be stabilised, flattened and mended prior to consolidation. Detail image of: G. Gerrits, *Composition 2-5-52, 1952*, oil and gouache on canvas, 55 x 35 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. SZ2141.

[48] Michel, F., Funori and JunFunori: two related consolidants with surprising properties, in: *Symposium on Adhesives and Consolidants for Conservation: research and applications* (2011) pp 7-10

Additionally, the presence of a (non-original) varnish layer can further complicate matters. Aged natural resin varnish layers can be stiff and brittle, inducing cracking in the less stiff paint layer. Their presence may also act as a consolidant, holding lifted, delaminated or flaking paint in position. This attribute may be especially true in the case of non-original varnishes, and their removal may exacerbate the delamination of paint flakes. Conversely, the presence of non-original varnish in cracks between cupped paint may prohibit the flattening and ability to consolidate these defects. It may be opportune to first remove varnish layers prior to consolidation, or to act simultaneously. The gel tissue compress system outlined in the Brochure on *Varnish Removal* will remove varnish from cracks effectively.

In emergency situations, such as imminent paint loss from the surface due to exposure to excessive moisture (flooding or otherwise) or prior to handling and treatment, it may be necessary to affix a paper **facing** to the flaking, crumbling, lifting or tenting paint for a short period of time. It may also be necessary to attach a facing when larger interventions are necessary to rectify structural damage to the support (either canvas or panel). Short-term facings and the consolidant required to attach them should be completely reversible without causing any adverse effects to the paint and ground layers. It may be opportune to add these facings prior to moving the art work, even prior to removal from the wall. Where possible, facings are made with thin pieces of acid-free, wet-strength paper as these exhibit minimal shrinkage and deformation upon drying. Japanese papers, such as Kozo (mulberry), Gampi or Mitsumata, are particularly prized for facing flaking paint areas.[49] The different fibres provide divergent properties to the resulting paper.

Many different adhesives have been used to adhere facings. Best practice suggests using a viscous adhesive that will not penetrate the paint layer, such as starch-based or cellulose-based paste mixtures.[50] Cellulose ethers dissolved in water or alcohols can be most useful for this purpose. Traditionally, dilute concentrations of animal glues are used. Facing papers can be pre-coated with the adhesive mixture and reactivation with appropriate solvent (or water) can occur in-situ. Other adhesives may have to be selected for water-sensitive paint surfaces. Adhesives that modify the appearance of the painting or result in tidelines on drying should be avoided.

Additionally, the painting may require pre-treatments to ensure that the damaged paint can be re-adhered in the correct position. Often with paint delamination and flaking, the support will need to be re-tensioned or elongated to allow space for compression set cupped paint to be laid flat. This is especially important for problems that are present over the full paint surface or in one specific colour. Pre-tensioning canvas paintings to ensure that lifted paint flakes have space to settle back into plane is essential to ensure the best practice approach for conserving paintings on textile supports. Structural treatments on panel paintings may need to be carried out by specialist conservators prior to implementing any surface treatments. Panels presenting compression-set derived from inadequate framing or induced by cradles applied to the reverse of the original support will need to be conserved by specialist conservators who are able to release tensions in the support in order to create space for tenting or raised paint flakes. Our advice is to seek expert advice in these cases. Similarly, paintings on metal supports that present flaking may need specialised treatment strategies in order to resolve consolidation issues.

A wide variation of tensioning systems and techniques should be in the conservators' 'tool-box', especially for canvas paintings. Tension tabs can be attached to tacking margins and used to apply lateral force without taking the canvas painting from the secondary support.

[49] *https://www.kamimorifoundation.com/projects*
https://store.hiromipaper.com/collections/japanese-papers/kozo-mulberry-paper

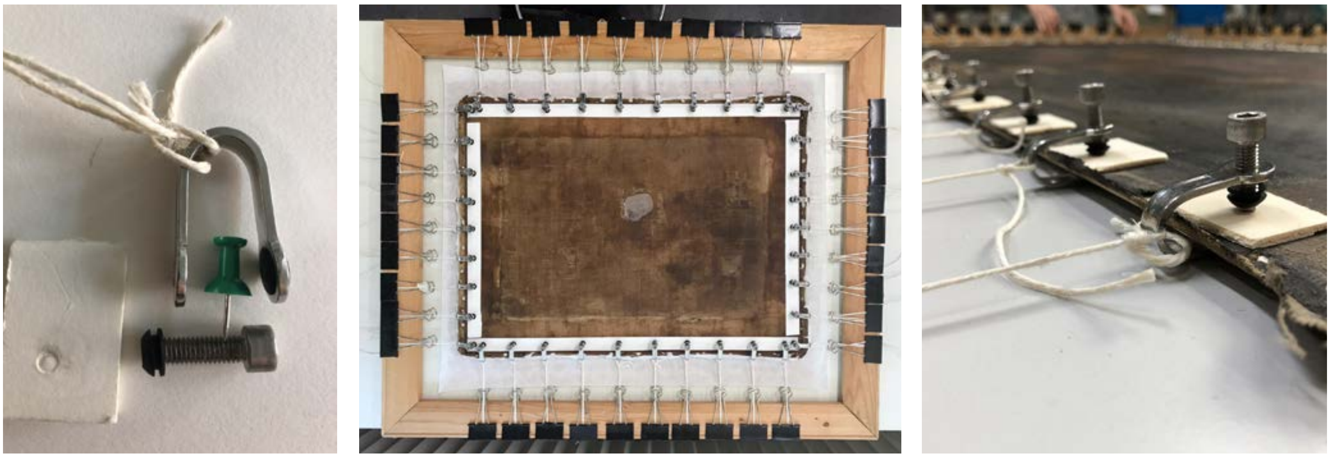
[50] *https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/canadian-conservation-institute-notes/emergency-treatment-water-damaged-paintings.html*

S. van den Berg, *Composition 1*, 1977, acrylic on canvas, 62 x 75.5 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. BK25250. Prior to consolidation of the tenting and flaking paint, the canvas, which had severe water damage, required humidification, stretching and flattening. (Above, seen in raking light conditions, Below, in daylight conditions).

Prior to treating the severe cupping and structural damage of this painting on canvas, a facing was applied.

If unmounted, there are a number of different techniques to tension textile supports with degrees of force application. Rigid supports may pose more problems as the support may not be stretched to provide additional space. Maintaining an overall curvature may be the only option to provide enough space for tented paint to return to a flat position! More information can be found in the Brochure on *The Structural Conservation of Canvases and Panels*.

In general, damages that are localised, resulting from mechanical damage or handling, can be treated with a more confined or restrained treatment. Cracking, cupping and flaking paint (i.e., types of damages that expose the lower layers of the ground and support) will more easily lend itself to treatments where the consolidant has a slightly higher concentration and can be applied with a brush or via a syringe. Powdering or crumbling paints are better treated with lower concentration consolidants applied with misting techniques or other techniques that do not require direct contact with the surface, as a brush is more likely to pick up material from the surface.
A facing paper, typically light-weight Japanese paper, can be used as a barrier to avoid pick up of loose paint during the application of the adhesive.[51]



Tension tabs can be attached to tacking margins and used to apply lateral force to the support. (Image source: Kate Seymour, SRAL).

[51] See: Michel F., Funori and JunFunori®: Two Related Consolidants with Surprising Properties, *CCI Symposium 2011: Adhesives and Consolidants for Conservation: Research and Applications*, Ottawa, 17–21 October 2011 and: Geiger T., Michel F., *Studies on the Polysaccharide JunFunori Used to Consolidate Matt Paint*, *Studies in Conservation*, Vol. 50, (2005) - Issue 3 pp 193-204, for more information on this technique using Funori and Junfunori.

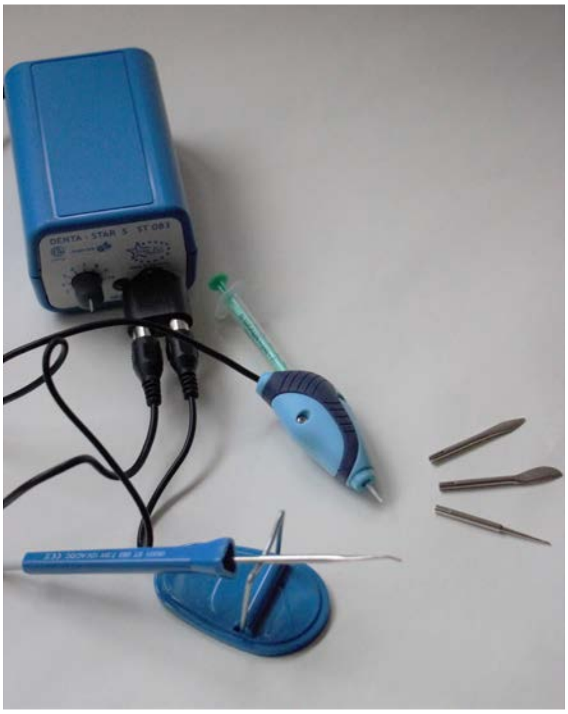
Consolidation Tools

A number of tools and materials typically used for consolidation treatments include:

- Small, pointed, soft brushes in a variety of shapes and sizes,
- Hand tools for lifting flakes and manipulating paint film, (e.g., micro-tweezers, micro-spatulas, scalpels, bamboo skewers, (and if available) vacuum pick-up tweezers),
- Heated spatula with a variety of different sized spatulas and/or tacking irons,
- Hot air pen or radiant heat tool,
- Stirring hot plate for mixing and warming adhesive solutions,
- USB coffee cup warmer,
- Wet-strength tissue or machine-or hand-made Japanese paper for facings,
- Syringes in a variety of sizes (for application of the consolidant), - micro-syringes may be optimal for inserting fluid adhesives beneath paint flakes,
- Silicone release paper, or silicone-coated release Melinex,
- Flat weights made from lead (shot), iron or glass, or sand bags, with a variety of coverings,
- Polyethylene foam sheets to apply weight and hold flakes in place while the consolidant is drying,
- Rice bags to assist drying,
- Humidification materials, such as Dahlia sprayer or blotter, or nebuliser,
- Spray equipment e.g., ultrasonic mister, pneumatic spray gun, air brush,
- Gor-tex or Polartex textiles to allow moisture vapours to pass through,
- Ventilation sources (fume hood, ventilation trunks, or portable extraction units),
- Stereomicroscope or Optivisor (magnification source),
- Vacuum hot table, suction table or variable suction plates (such as the Mitka suction table (to be used with or without heat)),
- Appropriate solvent for removing excess adhesive,
- Cotton swabs and tissue to absorb excess adhesive.

An example of some of the tools used to consolidate flaking paint: Heated spatula and heated syringe for warming the adhesive, small pointed soft brushes and hand tools, cotton swabs, consolidation medium, silicone release sheet.

A hot air pen produced by Willard.



A small hot spatula and glue warmer with a variety of heads for consolidation, and warming application syringe, produced by Denta-Star.

A hot spatula with different heads for consolidation, produced by Restauro-Technika.

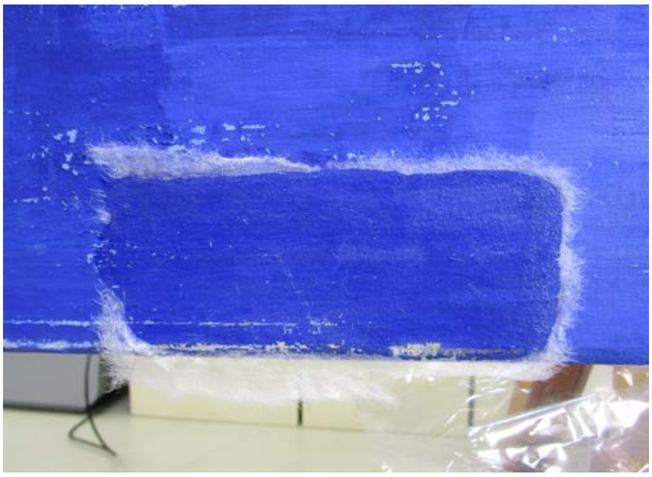
Choosing the adhesive for consolidation

When choosing a consolidant and its application method, a number of factors should be taken into account. Firstly, the composition and solubility properties of the painting's materials should be considered, as these will dictate which consolidants will be compatible with the paint and ground layers. Further, the paint and ground layers' sensitivity to heat, moisture and solvents should be considered, as should their mechanical properties, such as stiffness and flexibility. The type of adhesion or cohesion failure presented should also be noted, as this will affect factors such as the point of access to introduce a consolidant, and the porosity of the paint and substrata requiring consolidation.

It is important that the adhesive that is used for consolidation treatments has the right properties for the job at hand. The rheological properties, the ability of the adhesive to wet and bond to the substrates, its setting (or curing) time, and its aging properties should be taken into account before commencing consolidation. Generally, it is best to choose an adhesive that is 'compatible' with the original binding medium and preparation materials used by the artist. Cracking, cupping and flaking paint (i.e., types of damages that expose the lower layers of the ground and support) will more easily lend itself to treatments where the consolidant has a slightly higher concentration and can be applied with a brush or via a syringe. Powdering or crumbling paints are better treated with lower concentration consolidants applied with misting techniques or other techniques that do not require direct contact with the surface, as a brush is more likely to pick up material from the surface.

The adhesive choice will, therefore, be determined by chemical composition and by preparation of the solution. All adhesives chosen as consolidants need to be able to form a film on curing. The adhesive can be applied in fluid form as a solution (that is, dissolved in an appropriate solvent) or as a hot-melt. The first form a film on solvent evaporation, while the second on cooling. The molecular weight of the adhesive and its ability to wet a surface are important factors to consider, as should be the concentration of the solution and the application method. Adjusting the viscosity of the solution by altering concentration will improve flow and may reduce shrinkage on film forming. At times it will be necessary to have an adhesive that is viscous while in other cases a

Choosing an adhesive will be dependent on a variety of factors. (Image source: Kate Seymour, SRAL).



Mock-ups of the paint can be made to trial a variety of adhesives that may be suitable for consolidating paint. Here, a number of different natural and synthetic binding media were tested for consolidating matte and powdery paint, before trialling on the painting itself.

more fluid variant is optimal. It is essential for a successful consolidation treatment that the adhesive flows to the area where it is needed and that once there it has enough bonding power to reattach fragile paint.

Glues used in past treatments to resolve an ongoing problem may impede the application of fresh adhesives. In such cases, even if the adhesive used in the past is not considered the most appropriate, the same adhesive may need to be selected again. Over-consolidation or providing an adhesive with a higher bonding power than the original paint should be avoided, as should starving the adhesive bond line which results in providing too weak adherence.

Further factors surrounding the painting or painted surface should be taken into account, such as the storage and display conditions in which the artwork will be kept (and by extension, the effect these will have on the further aging properties of both the artwork and the consolidant) and what impact the consolidation material may have on any future treatments that may be necessary, whether during the current overall treatment round, or further into the future. The final consideration should be whether the artwork requires local treatment, or whether overall consolidation is required.

Having a wide choice of adhesives to choose from will assist in the critical selection for the right adhesive for the task in hand. The different types of adhesive and cohesive damage that can be found in paint and ground layers are described below.[52]

The chosen adhesive should be stable, reversible (when possible, such as for use with facings) and slightly weaker than the adhesive forces that exist within the paint layers and their stratigraphy. It should have a glass

[52] The Modern Paint Damage Atlas, Adhesion and Cohesion changes: *https://paint.tool.cultureelerfgoed.nl/phenomena/adhesion-cohesion-changes*

transition temperature (Tg) above room temperature, to avoid adhesive failure, cold flow or creep in normal storage or display conditions. The physical and chemical compatibility of the adhesive with the original material and the aging properties of the adhesive should be considered (potential yellowing and solubility in solvents over time). The working properties of the adhesive should also be considered. These include the flexibility of the adhesive, it's hygroscopicity, shrinkage on evaporation and rate of evaporation, possible methods of application and surface tension and capillary action (i.e., wicking ability). Finally, potential visual alterations to the paint layers, such as saturation, staining or changes in gloss should also be considered and understood. The shelf-life of the adhesive can also be a selection criterion.

Overview image of: G. Claassen, *Windmill in the winter*, ca. 1900-1949, oil on canvas, 73 x 55 cm. Collection of the Cultural Heritage Agency of the Netherlands, Nr. K14. Seen in raking light. Mechanical damage and poor environmental conditions have resulted in spiral cracks and stretcher bar cracks in the paint and ground layers.

Consolidation Media

The following consolidation adhesives (binding media) are commonly found in a conservators' tool kit:

Natural Binding Media

Protein-based glues

Protein based glues have been available for centuries and remain important adhesives in the conservators' toolkit. They have been used in the conservation of many different objects such as furniture, paintings and books and other paper-based artworks. Their behavioural properties and deterioration pathways are well understood by artists and conservators alike. The most common sources of collagen-based adhesives in conservation are animal skins (such as rabbit) or fish glues (such as sturgeon bladder). Collagen consists of long protein molecules composed of naturally occurring amino acids that are linked in a specific sequence by covalent peptide bonds.[53]

Animal skin glues and purified gelatine are commonly used in conservation. Hide glues are primarily derived from bovine skins and those of smaller mammals, although connective tissue may also be used. Strong hide glue types are often called carpenter's glue, and have been used in the past for the consolidation of wood or other solid materials. Typically, these glues have a too high bond strength to be useful for paint consolidation, though they have been used frequently as such throughout history. Skin glues from smaller animals, such as rabbits or goats, can provide a good glue for consolidation, especially if used in a dilute form. These are typically the basis of Italian *colletta's* or used in French or Spanish glue-paste linings. Some manufacturers mix rabbit skin glue with bovine hide glue to alter its properties.

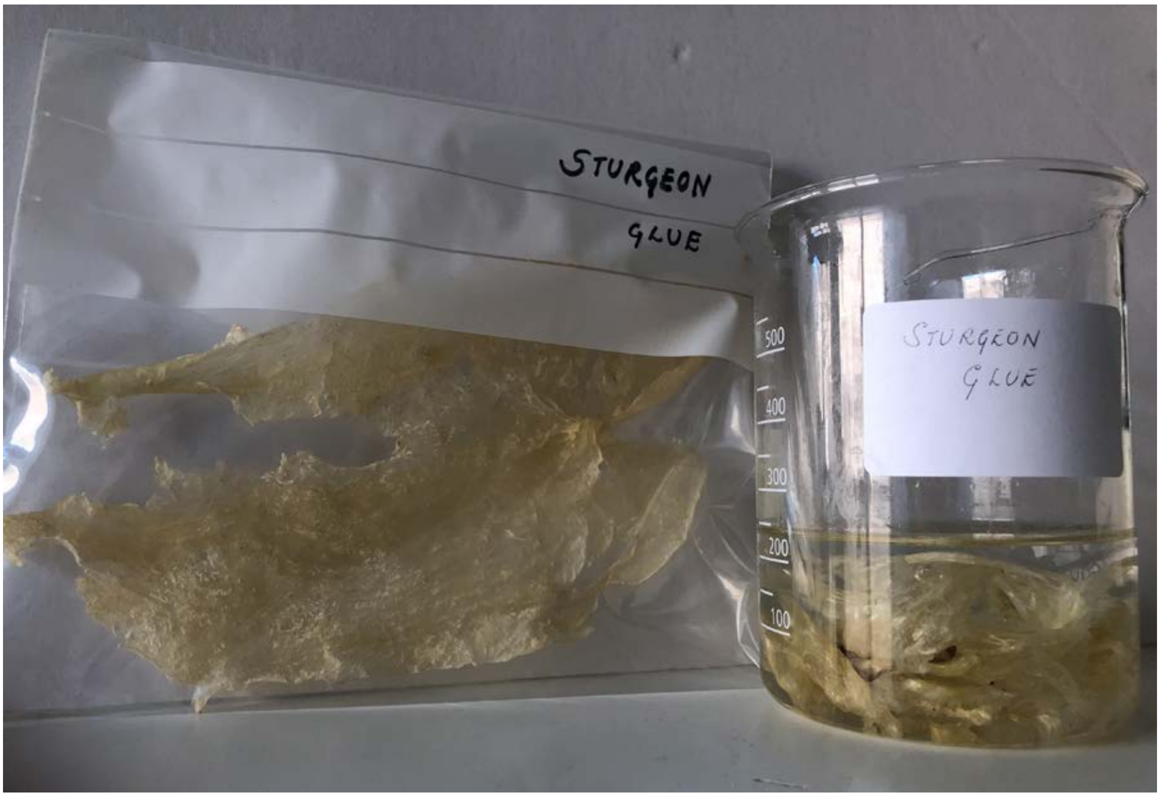
Today, these glues are made in bulk by chemical processing. The animal skins are subjected to acid/base reactions to remove excess hair and fat from the skins and extract the collagen. The derived glues are solidified and the resultant film crushed to a powder or flakes. Alternatively, pellets or beads can be extruded from the processed mass. Note also that it can be assumed that most animal glues contain preservatives of some kind (e.g., sulphur dioxide).[54] The dried material will have a long shelf-life, but the glue, when dissolved in water, will denature quickly and grow mould after a few days.

Purified gelatine, the active ingredient of any collagen-derived glue (pure denatured collagen), may be obtained from either skin or bone sources and is supplied in the form of thin sheets, plates or powder.[55] It is clear, colourless, light resistant and has a low viscosity.
A number of industrially manufactured cold liquid animal glues are available that have modified properties and a long shelf life. These glues usually contain additives that alter their natural behaviour, extending the working time at room temperature, or decreasing the propensity for biodeterioration and reducing the dried film's sensitivity to moisture. Given the range of additives that may be present in industrial glue formulations, minimally modified glues represent the safest option for conservation.[56] Typically, food quality gelatine can be used without problems.

Soluble gelatine is transformed from collagen by denaturation, a process achieved by hot water extraction after swelling in cold water. During extraction, the bonds (predominantly hydrogen bonds) in the triple-helix structures of the collagen are broken so that it separates into disordered 'random' coils of single protein chains, thus completing the transition to gelatine. In perfect conditions gelatine is pure denatured collagen.
The temperature at which denaturation (T_d) takes place is dependent on the proteins of the particular collagen source. The average adult mammalian T_d is 40-41°C, for cold water fish species (such as cod fish glue) it is approximately 10-15°C and for Isinglass, sturgeon glue and other warm water species it is 29°C.[57] As a general rule, gentle processing is appropriate for the hides of young mammals as well as all fish skin and swim bladders, because they are rich in collagen and the collagen is not so strongly stabilised by the additional chemical bonds that develop in older mammals.
Conservators should note that when preparing a collagen-based solution, mild procedures should be employed.[58] Preparation temperatures for collagen-based glues are generally recommended to be around 55–63°C. However, there is little loss of gel strength on

[53] Schellmann N.C., Animal glues: a review of their key properties relevant to conservation, *Studies in Conservation*, Volume 52, 2007 - Issue sup1: Reviews in Conservation 8 pp. 55-66
[54] Schellmann N.C., 2007 pp 55-56

[55] Schellmann N.C., 2007 pp 55-66
[56] Schellmann N.C., 2007 pp 55-56
[57] Hickman, D., Sims T.J., Miles, C.A., Bailey A.J., de Mari M., Koopmans M., Isinglass/collagen: denaturation and functionality, *Journal of Biotechnology*, Vol. 79 (2000) pp 245-257
Schellmann, N.C., 2007, pp 56
https://www.norlandproducts.com/techrpts/fishgelrpt.html (accessed 30 Nov 2021).
[58] Luybavskaya, E.A., 'Investigation of properties of protein glues', in *ICOM-CC 9th Triennial Meeting, Dresden, Preprints*, ed. K. Grimstad, International Council of Museums, Los Angeles (1990) Vol. 1 pp 47–50
Gelita, 'Dissolution of gelatine', http://www.gelita.com



Natural binding media: Sturgeon Glue (Image source, Kate Seymour, SRAL).

heating at high temperatures (e.g. 80–90°C), even in the case of isinglass, but only if the solution is kept at these temperatures for no more than a few minutes.[59]

Sturgeon glue (also sometimes called isinglass) was mentioned by De Mayerne in the seventeenth century, but became popular in Western conservation toward in the twentieth century. It has had a long history of use in Eastern European and Russian conservation practice and continues to be used there. Sturgeon glue is made from the air bladder of the Russian Beluga sturgeon fish, *Acipenser huso*. Fish glue is prepared from the waste products of various types of fish. Isinglass is the purest form of fish glue, made from the bladder of various species of fish such as the hake or cod, but often in conservation the terms sturgeon glue and isinglass are used interchangeably. Isinglass can be darker or yellower in colour than sturgeon glue, and less soluble in water.[60] Because sturgeon glue has a low viscosity and flows at room temperature, it can be used cooler and remains liquid longer than other animal glues.[61] Cod fish glue (derived from skin and bones of cod fish) is also commonly used by conservators. In paintings conservation, sturgeon glue is the preferred animal glue as it has a high collagen content, great strength at a low concentration, is nearly colourless, is very flexible and has the least shrinkage of all the collagen glues. It has a low surface tension and thus flows well beneath paint flakes. It forms a reversible sol gel, which is not stiff at room temperature. Just as other collagen adhesives, sturgeon glue is compatible with the original materials of older artworks, which contain similar glues as the size layer, and may even reactivate this layer when applied as a consolidant. Unfortunately, sturgeon glue is becoming harder to source, as it is considered an endangered species. Some countries ban the import of sturgeon products.

The ability to form a rigid gel on cooling, which can be repeatedly reliquefied by reheating, is one of the unique properties of collagen-based glues. The temperature at which gelation of the glue solution occurs (T_{gel}) depends mainly on the collagen source, but is also affected by the

59 Gelita, ‘Dissolution of gelatine’, http://www.gelita.com

60 Petukhova T., Bonadies S.D., Sturgeon glue for painting consolidation in Russia, *JAIC* 1993, Vol 32, Nr 1, Article 3 pp 23 to 31 *https://cool.culturalheritage.org/jaic/articles/jaic32-01-003.html*

61 von der Goltz, M., I. Birkenbeul, I. Horovitz, M. Blewett, and I. Dolgikh. 2012. Consolidation of flaking ground and paint. In:Stoner J.H., Rushfield R., (eds) *Conservation of Easel Paintings*, New York: Routledge. Pp 369-383

Natural binding media: (Jun)Funori

degree of protein cleavage. Gelation temperatures decrease with lower denaturation temperature (T_d) and also with increasing cleavage of the molecules. Mammalian gelatines gel at around 30–35°C, and fish gelatines gel at around 8°C.

The strength of the gel of any collagen-based adhesive, known as Bloom strength, is measured in grams (g) or in Bloom grams (gB) and is a measure of the strength and stiffness of the gel. It reflects the average molecular weight (AMW) of its constituents, and is usually between 30 and 300 Bloom (< 150 is considered to be a low Bloom, 150–220 a medium Bloom, and 220–300 a high Bloom).[62] Gel strength also shows a linear correlation with the degree to which the protein solution renatures during gelation. Gel strength is influenced by factors such as the presence of salt, with strength decreasing as the concentration of ions in solution increases. Sturgeon glue has a medium to high Bloom strength, fish gelatine a low to medium Bloom strength, and rabbit or hide skin glue generally medium to high strength.[63] It is advisable to have a number of different animal glues with different Bloom strengths in the conservation laboratory.

These adhesives have a short shelf life once it is in solution (so ideally small amounts should only be made at any one time)[64] and it loses its strength if it is overheated or heated multiple times. Because it is a natural binding medium, it is also vulnerable to attack by pests and microorganisms. Sturgeon glue is quite expensive in comparison with other consolidation media, as it is derived from the bladder of the endangered beluga sturgeon. Collagen glues will degrade over time. This property can be seen as either an advantage or disadvantage. Solutions of collagen can be kept in the refrigerator for some time, especially if kept in a clean container, but are readily subjected to micro-fungal attack. It is advisable to store in syringes without any air.

The choice of adhesive for conservation purposes may also be dependent on the pH sensitivity of the substrate. The pH of various animal glues is also of importance, as it has an influence on the viscosity of the glue. The viscosity of the gel increases when the pH of the solution shifts away from its isoelectric point (the pH at which all positive and negative charges within the molecule are balanced and the molecule carries no net electrical charge). If the electrical potential of the ions is unbalanced, solution viscosity and T_{gel} increase, as well as the capacity for water-sorption and swelling ability, while the gel strength decreases.[65] Hide glues and rabbit skin glues have a pH of between 5-7, although wider variations are possible, sturgeon glue has a pH of between 6.0-7.5, and other fish glues have pH's as low as 3.5-5.0, although higher pH values may be possible.

Funori

Funori is a traditional adhesive used in Japan for centuries by scroll makers, and has been employed in recent decades for the consolidation of friable, matte paint in Western conservation practice. Funori is a polysaccharide extracted from the red alga genus *Gloiopeltis*. Funori has variations in quality and properties, due to varying harvesting and processing methods. Michel (2011) found that the pH of 10 different samples varied from 6.4-10.4.[66] Funori is sold as a fibrous matt and requires careful processing before use.

Research in the early twenty-first century led to changes in the processing method, resulting in a more highly purified product known as JunFunori, a product with more consistent properties, although there were some issues with fluctuations in quality around 2007 after the rights to developing JunFunori were sold to a new producer.[67] JunFunori is made only from *Gloiopeltis furcata* and after processing comes as a white powder. It is flexible, has a low viscosity, a stable pH and dries matte,

[62] Schellmann N.C., 2007, pp 55-66
[63] Schellmann N.C., 2007, pp 55-66
[64] All collagen glues can be stored for longer in a syringe in the refrigerator.

[65] Haupt. M., Dyer D., Hanlan J., An investigation into three animal glues, *The Conservator*, Vol. 14 (1990) 10-16.
[66] Michel, F., Funori and JunFunori: two related consolidants with surprising properties, in: Symposium on Adhesives and Consolidants for Conservation: research and applications (2011) pp 1-14
[67] Michel, F., (2011) pp 1-14

making it a good choice for consolidating matte, underbound paint.[68]

Funori is also considered suitable as a consolidant, as when good quality Funori is used, excellent results can also be achieved with stable properties (pH, aging, flexibility).[69] In viability tests JunFunori was as resistant to biological attack as other consolidants.[70] Both Funori and JunFunori are suitable consolidants for matte, powdery paint layers. They minimise the risk of optical changes such as the formation of tidelines, darkening or unintended gloss. Their adhesive strength is weak, but can be reinforced by the application of multiple layers of low concentration consolidant, or the addition of another medium, such as sturgeon glue. Funori and JunFunori both have the ability to be used as the cleaning agents for the removal of water stains and other imbibed dirt in powdery paint layers, occurring simultaneously during consolidation.[71]

Semi-Synthetic Binders

Cellulose ethers

Modified cellulose-derived ethers, such as methylcellulose (MC) and carboxyl-methylcellulose (CMC) have been used in paper conservation since the 1950's and hydroxy-propylcellulose (HPC) has been used in easel painting conservation since the 1980's. HPC is soluble in polar and partially in non-polar solvents, whereas MC and CMC are only soluble in polar solvents. HPC (also known by its tradename Klucel) comes in several viscosity grades,[72] however only Klucel G is used in painting conservation today as the higher viscosity grades are found to be unstable, and many will discolour and loose flexibility under moderate aging conditions.[73] Klucel G is able to swell in non-polar solvents alone.

Klucel G dries matte and tends not to saturate paint as much as some other consolidants, so it can be employed when dark, underbound colours require consolidation. When Klucel G is dissolved in polar solvents such as ethanol, the properties of the consolidant will differ to when dissolved in water. Klucel G is often used as a gelling agent in conservation especially in varnish removal, and has a weak bonding strength.[74]

Cellulosic adhesives in general are prone to suffering photochemical degradation, discolouration and subsequent loss of adhesion. Accelerated aging tests of some HPC adhesives resulted in a shiny, milky film that contracted and cracked.[75] It is thus best to remove any residues from the surface after consolidation. Excess can be removed with water or alcohols depending on the solubility of the surface to which it is applied.

Semi-synthetic binders: Ethyl Cellulose

[68] Michel, F., 2011 Funori and JunFunori: Two related consolidant with surprising properties, in *Canadian Conservation Institute Symposium Ottawa*, pp 1-14

[69] Michel, F., (2011) pp 1-14

[70] Geiger T., Michel F., *Studies on the polysaccaride Junfunori used to consolidate matte paint*, 2005, in: *Studies in Conservation 50(3)*, pp 193-204

[71] Geiger T., Michel F., (2005), pp 193-204
Mauny-van den Burg, J.M, Veerman A., van den Berg K.J., *Trials and Tests for the Consolidation of Matte, Powdery Paints. Two Case Studies.*, 2016, in: *Colore e Conservazione, 13–14 November 2015, Politecnico di Milano. Padova*, pp 185-193

[72] Klucel EL: MW=40,000 g/mol, Klucel E: MW=80,000 g/mol, Klucel L: MW=95,000 g/mol, Klucel J: MW=140,000 g/mol, Klucel G: MW=370,000 g/mol, Klucel M: MW=850,000 g/mol, Klucel H: MW=1,150,000 g/mol. See: https://www.conservation-wiki.com/wiki/Paint_Consolidation

[73] Geiger, T. and F. Michel. 2005. pp 193-204. *https://doi.org/10.1179/sic.2005.50.3.193*

[74] See: Feller, R.L. and M. Wilt. 1993. Evaluation of Cellulose Ethers for Conservation. The Getty Conservation Institute. doi: *https://www.getty.edu/conservation/publications_resources/pdf_publications/pdf/ethers.pdf*
For a full analysis and discussion on the different cellulose ethers and their properties see: Horie C.V., *Materials for Conservation: Organic Consolidants, Adhesives and Coatings*, 2010 (2nd ed.) Elsevier LTD, Oxford

[75] Geiger, T. and F. Michel. 2005. pp 193-204 *https://doi.org/10.1179/sic.2005.50.3.193*

Synthetic Binders

PVA adhesives

PVA adhesives (poly vinyl acetates, PVAc's and poly vinyl alcohols, PVAl's) have been used as consolidants since the 1930's. They were used as solvent solutions, formulated from solid resins, or as aqueous dispersions. These adhesives are based on a co-polymer consisting of ethylene and vinyl acetate. Many variants exist with manufacturers carefully manipulating the proportional degree of ethylene to vinyl acetate. The higher the degree of vinyl acetate, the higher the molecular weight, viscosity, resistance to flow, etc. Low molecular weight variants can be produced where the ethylene monomer outweighs the vinyl acetate monomer. These adhesives have different properties and the dispersions typically remain water soluble on aging as less cross-linking occurs. However, these variants have less adhesive strength and more elasticity. Specially formulated EVA (ethylene vinyl acetate) products are used both as solid resins and as dispersions in the conservation field.

Synthetic Binders: Jade 403N

In America, various grades with differing properties have been produced as resins and then discontinued by Union Carbide (AYAA, AYAC, AYAF, AYAT) and as dispersions, such as Elmer's glue. European manufacturers have also had a long history of production of these glues, which are sold under different trade names. PVA resins are distributed under the name Mowiol (these products are typically sold as a solid which can be dissolved), whereas the European dispersion adhesives variants are known under the brand Jade or Mowilith (these resins are formulated as dispersions). These materials are subject to market interest and often undergo shifts in formulation or discontinuation. EVA variants of PVAc dispersion adhesives are sold under the trade name BEVA D8 and Evacon R.[76]

Evacon R was especially formulated in the early 1980s by ConservationXDesign (CXD) to have a neutral pH, contain few plasticisers and to be (water) reversible.[77]
The product was produced for lamination of paper but has found other uses within a broad range of conservation treatments. The adhesive does not off-gas and can be safely used in adjacent to acid sensitive artistic materials, such as photographs or silver. The product may contain a small portion of calcium carbonate and a cellulosic thickening agent, both of which aid the long-term stability of this material.
The formulation is relatively viscous but flow can be adjusted by thinning with water. Dry films remain water sensitive. Alternative versions are available but have not undergone as much rigorous testing for conservation use.[78] Lineco, USA produces an equivalent low molecular weight PVAc/EVA dispersion adhesive for framing purposes.[79] The product was also specially designed for conservation purposes and the dry film remains soluble in water after aging.

PVAc's tend to have quite high acidic values, become brittle and discolour, and have an excessively high adhesive strength. Their fluctuating availability and negative properties have led them to be largely replaced by acrylic resins. Many of the vinylic dispersions also off-gas acetic acid and cross-link to insoluble films.

[76] *https://www.talasonline.com/images/PDF/Instructions/beva_d8_instructions.pdf*
[77] *https://www.cxdinternational.com/equipment-tools/adhesives-pastes-consolidants/cxd-evacon-r-conservation-adhesive-25kg-suevar0005*

[78] Flock H., Neue Untersuchungen zur Rissschließung in Leinwandbildträgern: Uni- und biaxiale Zugprüfungen an Prüfkörpern aus verklebtem Leinengarn und -gewebe sowie freien Klebstofffilmen (New Investigations on Adhesives for the Tear Repair in Canvas Paintings: Uni- and biaxial Tensile Tests on Specimens of mended Threads and Canvas as well as free Adhesive Films), *Kölner Beiträge zur Restaurierung und Konservierung von Kunst- und Kulturgut*, Digitale Edition Band 2. Köln 2014. *urn:nbn:de:hbz:832-epub4-6019*
[79] *https://www.lineco.com/white-neutral-ph-adhesive.html*

BEVA 371

BEVA 371 is a mixture of ethylene vinyl acetate (EVA), synthetic resin, and microcrystalline wax.[80] The formula was created by Gustav Berger and William Russel in 1969 as a synthetic lining adhesive for use on vacuum hot tables. The original formulation has undergone a number of changes since its commercialisation in the early 1970s. The original formula contained a mixture of Elvax (ethylene vinyl acetate [EVA] copolymer), Ketone Resin N (polycyclohexanone) [and subsequently Laropal K80], A-C copolymer (EVA), Cellolyn 21 (phthalate ester of hydroabietyl alcohol) and paraffin, which was dissolved in aromatic hydrocarbons (37–40 mass% solids in a toluene/naphtha solvent mixture).[81] The original formula was patented by Gustav Berger and today two patented variants are sold – one in the USA via Conservators Products Company (CPC), New Jersey and one in Europe via CTS, Italy. CPC collaborated with Berger in the 1990's to reformulate the commercial product after Laropal K80 (BASF) was discontinued.[82] Their formula, since 2008, has contained an aldehyde ketone resin (unspecified), and is sold under the trade mark BEVA 371b.[83] This product can be distinguished from the original formulation by its slightly yellower tone.

BEVA 371

In Europe, CTS substituted in 2010 the ketone resin with a urea-aldehyde resin called Laropal A81. Their formulation is a product based on ethylene vinyl acetate, paraffin, ketone resin, 40% solids content in aliphatic and aromatic solvents.[84] CTS sell this product under the trademark name **Gustav Berger's Original Formula 371®**.

Lascaux, Switzerland formulated a Heat-Seal Adhesive 375 based on the early formulations published by Berger and Russel. This product is still available.

BEVA 371 was formulated in a number of different formats, including BEVA 371 granules (produced solely in the USA, which can be diluted to the desired concentration by conservators), BEVA 371 gelled in solvents (the granules pre-dissolved in toluene and naphtha's – and are often then further diluted by conservators) and BEVA 371 film. BEVA 371 was formulated as a strong and flexible adhesive with a softening temperature that was well below its melt temperature. This ensured that the adhesive, on heating to c. 65-75°C became tacky but did not flow, reducing penetration of the adhesive into substrates and permitting nap bonds to be formed. The melt temperature of the higher molecular weight components is around 115°C. Gustav Berger's Original Formula 371®/ BEVA 371b is soluble in aromatic hydrocarbons, which makes it potentially suitable as a consolidant for paintings that are water sensitive or on paintings previously infused with wax or wax-resin mixtures. Recent considerations posit however, that the activation temperature of BEVA 371 is detrimental to use for these legacy paintings, as at 80°C separation of the beeswax-resin adhesive will occur, causing the more acidic resin to be left behind.

BEVA 371 has had widespread use as a consolidant for diverse typologies of paintings. It has been used on matte paint films as it dries with a matte, waxy finish. It can be diluted and used hot or cold, although it is best to use it warm, as it is better able to flow into cracks and under flakes. It is thermoplastic and can be activated by heat at 65°C, though slightly higher temperatures are often utilised to ensure a better bond. One of the downsides of BEVA is that it is known to yellow over time, and its long-term stability continues to be investigated.[85] As a consolidant, it will change the physical and aesthetic characteristics of the surface to

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[80] Ploeger, R., Rene de la Rie, E., McGlinchey, C.W., Palmer, M., Maines, C.A., Chiantore O. The long-term stability of a popular heat-seal adhesive for the conservation of painted cultural objects. *Polymer Degradation and Stability*, (2014), vol. 107 pp 307-313.

[81] *https://cameo.mfa.org/wiki/BEVA_371*

[82] Formulation of CPC's BEVA 371: Toluene, Naphtha, DuPont Elvax 150 (Ethylene Vinyl Acetate Copolymer), BASF Laropol K80 (Cyclohexanone resin), Allied A-C Copolymer (Ethylene Vinyl Acetate Copolymer), Hercules Cellolyn 21 (Phthalate Ester of Hydroabietyl Alcohol), (Cellolyn 21 may have been replaced with Cellolyn 121 (tackifying resin) – 4% of formula. See: Denis Baltuskonis, Conservation DistList, 2008 Feb 5: *https://cool.culturalheritage.org/byform/mailing-lists/cdl/2008/0168.html*

[83] *http://www.conservators-products.com/pro1.html*

[84] *https://www.ctseurope.com/gb/400-gustav-berger-s-original-formula-beva-371-thinner-372*

[85] Ploeger, R., Rene de la Rie, E., McGlinchey, C.W., Palmer, M., Maines, C.A., Chiantore O., (2014), pp 307-313

which it is applied. **Please note: The authors would advise the use of this material as a consolidant as a last resort.**

Berger also developed an aqueous dispersion (BEVA D-8) and as a gel mixture of EVA, acrylic resin, and cellulosic materials (BEVA Gel). BEVA D-8 was designed as a consolidant for water sensitive paints.

Acrylic Resins

Acrylic resins have a neutral pH and better aging properties than PVAc's. They are also less expensive to make and are produced using greener technologies. Acrylics have been in use in the conservation field since the mid twentieth century. Acrylic resins in aqueous dispersions have good penetration and wetting properties, especially in dilute aqueous solutions.

Acrylic resins that can be dissolved in organic solvents include Paraloid B72 (Rohm & Haas, USA) and Degalan P550 (Evonik Röhm, Germany) [formerly known by the brand name Plexisol P550].[86] Of these two products, the best known and most used is Paraloid B72. Paraloid B72 is an ethyl methacrylate/methyl acrylate copolymer thermoplastic resin produced by the Dow Chemical Company. It comes as solid, transparent pellets. Paraloid B72 is expected to remain clear, colourless and soluble, in the same solvents in which it was initially dissolved, for at least 200 years, making it one of the most stable resins available to conservators.[87] It is soluble in xylene, acetone and 100% aromatic hydrocarbons and will swell in alcohols. Paraloid B72 has a high viscosity which makes it a good choice for re-adhering loose flakes and delaminating paint. It is less well-suited for cohesive issues within a paint film (powdering paint) or consolidating underbound paint as it leaves a glossy appearance. Paraloid B72 has a T_g above room temperature (40°C). As it is thermoplastic, Paraloid B72 can be activated with heat to flow and set lifting paint back into plane. Studies have shown that the mechanical properties of films cast with this material are dependent on the solvent in which it is dissolved. Furthermore, recent studies have shown that films yellow and embrittle on aging.[88]

Degalan/Plexisol P550

These acrylic resins have been used as consolidants, especially when dissolved in a hydrocarbon solvent. They have found use not only to lay down flaking paint but also to return full adhesion to paint layers delaminating from the ground or crumbling. Paintings are often fully encapsulated into an envelope, from which air is removed, and the dissolved resin is pumped into the envelope, impregnating the entire laminate structure. Heat can be used to encourage penetration and flow, either applied externally to the envelope, or subsequently after the solvent content has evaporated on a hot table or heated low-pressure envelope.
The authors acknowledge this tradition but advise to use it sparsely. The technique is especially used for treating delaminating acrylic or alkyd paints.

Aqueous acrylic dispersions include the Plextol range, including Plextol B500, Plextol D512 and Plextol D489, (currently produced by Synthomer in Germany) and Medium for Consolidation (Lascaux, Switzerland). As with all commercial acrylic dispersions, these contain surfactants which are included to hold the resinous material in suspension and prevent de-foaming. Fungicides may also be added to increase shelf life. These additives may migrate out of the dry films and coatings. These formulations are manufactured for the coating, adhesive and binding media (inks and paints) industries. The formulations are subject to change and discontinuation. Many well revered acrylic dispersion adhesives are no longer produced and thus while they

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86 von der Goltz, M., I. Birkenbeul, I. Horovitz, M. Blewett, and I. Dolgikh. (2012) pp 369-383 *https://www.ctseurope.com/gb/140-plexisol-degalan-p-550*

87 Feller, R.L., M. Curran, Bailie, C., Photochemical studies of methacrylate coatings for the conservation of museum objects. In: *Photodegradation and photostabilization of coatings*. 1981, American Chemical Society Symposium, Houston, pp 183–96

88 Vassort B., Pràznà V., Nguyen A., Kapalli B., Whitney N., Mevius R., Hehl V., Handor D., Shah N., Seymour K., Perversi G., How trustworthy is an adhesive? The suitability of adhesives for use in Conservation of Fine Art, *Florence Heri-Tech 2022: The Future of Heritage Science and Technologies*, pp 119–135 *https://link.springer.com/chapter/10.1007/978-3-031-15676-2_9*

may be found on objects they cannot be purchased.[89] These include, for example: Plextol D360, Plextol D541, Plextol D540.

There may be industrial equivalents that have very similar properties but have not been subjected to rigorous analytical testing by the conservation field. Substitutes include Dispersion K360 (introduced in the mid-2000s as a replacement for Plextol 360) and Dispersion B500 (a similar product to Plextol B500). Recent FTIR-ATR analysis of cast films has shown that there are regional differences in the product produced under the same brand name (for instance, Plextol B500).[90]

Locally produced acrylic dispersions can be utilised by conservators. It is recommended that these be brushed out on Melinex as thin and thick films and exposed to daylight containing UV radiation for one year. Half of the dried film should be protected from light exposure. Any product that yellows considerably should be discarded.

Lascaux Medium for Consolidation (sold under the name Lascaux 4176) was designed and formulated for the conservation field.[91] It is an aqueous dispersion of an acrylic copolymer based on acrylic ester, styrol, and methacrylic ester (including butyl acrylate, methyl acrylate and methylmethacrylate). Unlike other acrylic dispersions the formulation contains a low volumetric percentage (2%) of surfactant. It has excellent capillary properties due in part to the low molecular weight and low concentration of the polymeric content. This material was formulated in 2004 to replace BASF's discontinued popular acrylic dispersion Acronal 300D, which had been used since the 1960s for laminating paper.

Medium for Consolidation is a very fluid acrylic dispersion which has a pH of 8.5, and can be further thinned with water during application.[92] The dispersion has good film forming capacity at low temperatures and dry films can also be heat activated. Its low viscosity allows for good penetration and consolidating of loose, underbound

Lascaux Medium for Consolidation

paint. It has found use for consolidating (temper) paint layers applied to wooden supports, gilded surfaces, and acrylic paintings. As no additional solvents are required, it can be easily transported and used for treatments on-site. Once dry, it is soluble in esters, aromatic hydrocarbons, xylene, toluene, acetone, and methyl ethyl ketone (MEK). Studies on Medium for Consolidation report that it is a stable, flexible resin that retains its appearance over time without yellowing.[93] More recent studies, however, have questioned its yellowing properties on aging.[94] Lascaux also produce a wide range of other acrylic dispersions for paint mediums that can be bought independently, as well as a binder for acrylic paint.

Acrylic resins may be preferred to reattach paint layers that have adhesive issues such as flaking, cupping, delaminating and detached paint layers that are well-bound, as they are often glossy when dry/set, and therefore some are not suited for matte and underbound paint issues. When dissolved in solvents, they are suitable for paint layers that may show water sensitivity, or for works that have fungal issues, where aqueous solutions should not be used. And of course, for acrylic paint layers.

Poly(2-ethyl-2-oxazoline) (PEO) Resins

Aquazol is a poly(2-ethyl-2-oxazoline) resin which has been used by conservators since the 1990's. It is available

89 Down J.L., MacDonald M.A., Tétreault J., Williams R.S., Adhesive testing at the Canadian Conservation Institute-an evaluation of selected poly(vinyl acetate) and acrylic adhesives, *Studies in Conservation*, 1996, Vol 41, Issue 1 pp 19-44 *https://www.tandfonline.com/doi/abs/10.1179/sic.1996.41.1.19*
Down J.L., The evaluation of selected poly(vinyl acetate) and acrylic adhesives: A final research update, Studies in Conservation, 2015, Vol. 60, Nr 1, pp 33-54 *https://www.iiconservation.org/node/5455?fbclid=IwAR3LguVg7lpr7i4EXCZb_JfpVNCsOiqvdlWl4dpu6fHtnZGnNdHDcqBThNE*

90 Vassort B., Pràznà V., Nguyen A., Kapalli B., Whitney N., Mevius R., Hehl V., Handor D., Shah N., Seymour K., Perversi G., How trustworthy is an adhesive? The suitability of adhesives for use in Conservation of Fine Art, *Florence Heri-Tech 2022: The Future of Heritage Science and Technologies*, pp 119–135 *https://link.springer.com/chapter/10.1007/978-3-031-15676-2_9*

91 *https://lascaux.ch/dbFile/2274/u-od16/u-od16/The_Picture_Restorer_2010.pdf*

92 *https://shop.kremerpigments.com/elements/resources/products/files/81012e.pdf*

93 Hedlund, H.P. and M. Johansson. 2005. Prototypes of Lascaux's Medium for Consolidation. Restauro, 6: 432-439. *https://lascaux.ch/dbFile/2272/u-9ef2/Restauro_2005_06_medium_fur_konsolidierung.pdf*

94 Pataki-Hundt, A. 2018. Characteristics of natural and synthetic adhesives. Paper Presented at Consolidation & Communication: Materials and Methods for the Consolidation of Cultural Heritage. Hildesheim, Germany: Hornemann Institute. doi: *https://www.researchgate.net/publication/323167384_Characeristics_of_natural_and_synthetic_adhesives*

in a number of molecular grades, of which three are most popular with conservators. These are Aquazol 50, 200 and 500, with the higher the number, corresponding with a higher molecular weight.[95] The different molecular weights have different handling properties, so gloss, viscosity (and therefore flow), T_g, and adhesive strength can be controlled by mixing different molecular grades. Aquazol resins are soluble in a number of polar solvents such as water, methyl ethyl ketone (MEK), acetone, ethanol and isopropanol. These resins are insoluble in all hydrocarbon solvents.

Aquazol has good bond strength, is non-toxic, pH neutral, stable, does not shrink, stable and adheres to a variety of materials. Depending on the mixture and concentration of molecular grades used, it can be used as a consolidant for matte paint, but is also suitable when a gloss or sheen is needed. It can also be used to penetrate paint layers and aid in plasticising and relaxing cupped paint.[96] It has been used successfully to treat fire blistered paint surfaces. It can be used as a binder for retouching pigments and for filling materials. The resin has recently been used to formulate Golden's QOR watercolour brand paints for artists.[97]

Because it is a synthetic resin, it does not support mould growth, but it does have a high affinity to water. Concerningly, some conservators have reported that certain batches of Aquazol turned yellow in colour, either in solution or while stored in dry pellet form, and the lower molecular weight variants have also been noted to undergo cold flow while stored in environments of 50-70% relative humidity (RH) and 21-23°C. The greatest concern, however, is Aquazol's response to a higher RH, where films of the resin were found to become tacky at around 60-65% RH.[98] In such cases, the adhesive was seen to swell and, in a few instances, lose some of its adhesive strength.[99]

Aquazol is commonly used by conservators where surface appearance is paramount. The lower MW resins are especially suitable for consolidation of matte, powdering and/or friable paint and gouache. Aquazol 50 is often used for matte paint because it will more effectively penetrate the area to be consolidated. For example,

95 Aquazol 50: MW=50,000 g/mol, Aquazol 200: MW=200,000 g/mol, Aquazol 500: MW=500,000 g/mol.

96 Arslanoglu, J., Tallent, C., Aquazol as Used in Conservation Practice. *WAAC Newsletter*, (2003) vol. 25 (2) pp 12-18 *http://cool.conservation-us.org/waac/wn/wn25/wn25-2/wn25-205.pdf*
Arslanoglu, J. Aquazol as Used in Conservation Practice. *WAAC Newsletter*, (2004) vol. 25 (1), pp 10-15. *http://cool.conservation-us.org/waac/wn/wn26/wn26-1/wn26-105.pdf*

97 *https://www.qorcolors.com/*

98 Muros, V. Investigation into the Use of Aquazol as an Adhesive on Archaeological Sites. *WAAC Newsletter*, (2012) vol.34 (1) pp 9-11. *http://cool.conservation-us.org/waac/wn/wn34/wn34-1/wn34-103.pdf*

99 Arslanoglu, J., Using Aquazol: A brief summary. *Paintings Specialty Group Postprints* Washington DC: American Institute for Conservation, (2005), pp 107-110.

11.8: Aquazol

Regalrez 1094

Aquazol 50 in water can be used to replace sturgeon glue, as the low MW Aquazol does not have the shrinkage or gloss of sturgeon glue.[100]

Aquazol 500 can also aid with the plasticization and flattening of cupped/ tented paint because it will form the strongest bond (of the Aquazol resins). Thicker paint appears to require a dilute solution of Aquazol 500 in solvent applied in multiple applications for better penetration with the lower surface energy. The viscosity of Aquazol 500 can be exploited in order to fill voids without much shrinkage; multiple applications of a dilute solution can give the penetration and strength required.[101] One technique that may give the best results is to first consolidate with a solution of Aquazol 50 or 200 in order to achieve penetration (essentially pre-wetting with a low MW consolidant), followed by an Aquazol 500 solution to achieve a strong bond between the surfaces.[102]

Other synthetic resins

A wide variety of other synthetic resins have also been used as consolidants. One particular useful resin is Regalrez 1094. This is a hydrogenated hydrocarbon resin which has a low molecular weight and a T_g just above room temperature. It has found use in consolidating blanched paint surfaces as it will penetrate (or sink in) to aged oil paint surfaces. It is particularly useful at re-saturating or consolidating degraded paints containing organic dyestuffs. A higher molecular weight variant also exists, Regalrez 1126. This resin is more typically used in furniture conservation as it forms a more durable, scratch resistant film.

[100] Arslanoglu J., 2004, pp 10
[101] Arslanoglu J., 2004 pp 10

[102] Arslanoglu J., 2004 pp 10

Consolidation Methods

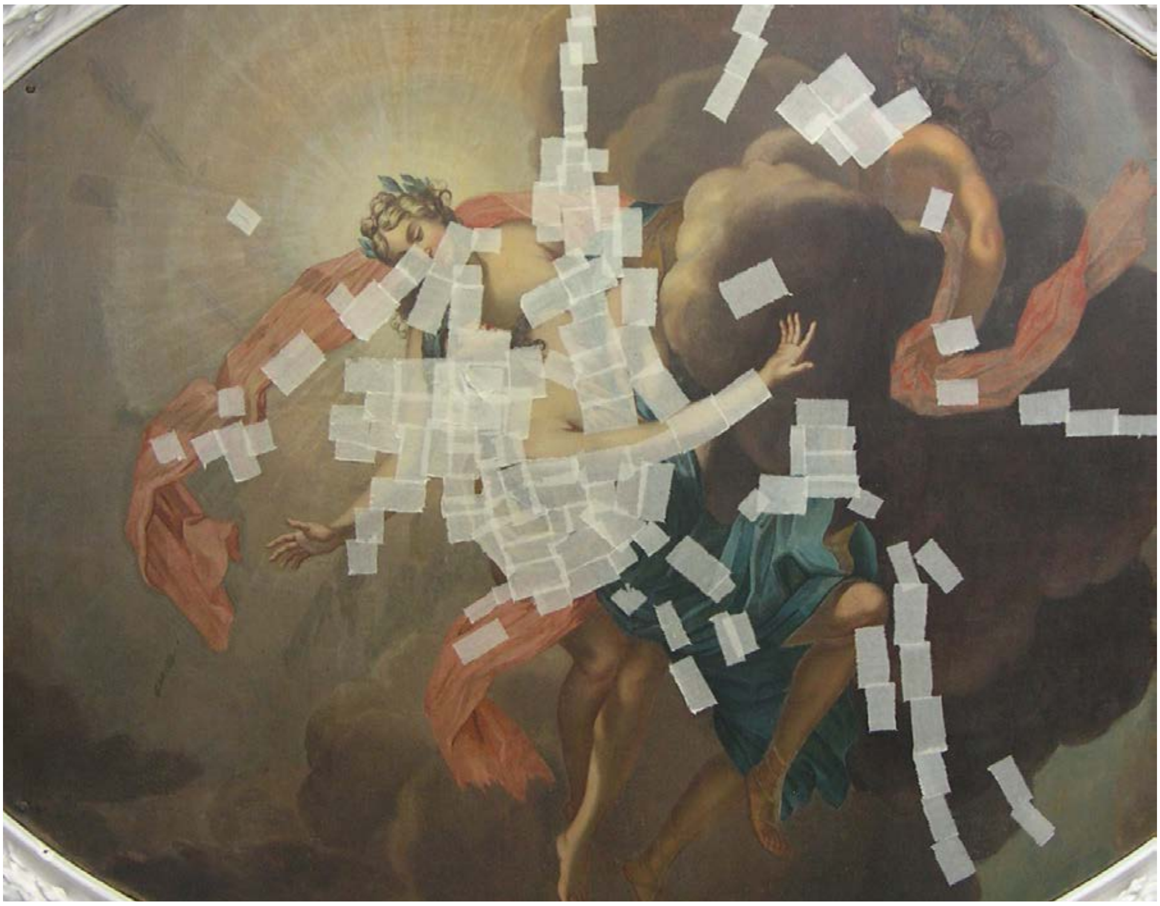
The method of consolidation required will be determined by the adhesive and/or cohesive issues presenting for treatment and the surface characteristics of the painting. The type(s) of adhesive or cohesive issue(s), the chemical and optical properties of the paint film, the location of the issues, and the magnitude of the degradation phenomena will influence the decision on a suitable consolidation technique.

Facings

As mentioned earlier, it may be necessary to affix a temporary facing to areas of loose paint layers to hold them in place, protect them until the artwork is ready for treatment, and during transport or movement (either from one location to another, or during manipulation during treatment steps). It is also possible to treat the loose paint layers through the facing as the facing will keep paint flakes in position. Facings are generally made of thin paper or tissue, or in an emergency, fabric. Non-woven synthetic or semi-synthetic papers can also be used.

A thin, wet-strength tissue will absorb and transmit water well, without excessive shrinkage or dissolving. Some tissues will shrink as they dry, so it is important to apply the tissue grain parallel to raised cracks to help draw gaps closed as the tissue contracts during drying. Non-woven tissue does not have a grain, and has minimal shrinkage on drying, making it ideal for facings. Small pieces of tissue are made with softly fraying the edges by painting lines on the tissue to create the desired dimensions and gently pulling the sections apart ('water-torn' tissue). These pieces of tissue are then placed carefully over the areas of loose paint, generally staggered to distribute stress evenly.[103] If it is difficult to get the tissue to conform to the textured paint surface,

[103] von der Goltz, M., I. Birkenbeul, I. Horovitz, M. Blewett, and I. Dolgikh (2012) Pp 396



Facings can be applied locally to flaking and loose paint, or over the entire surface. Here, pieces of Japanese tissue have been frayed along the edges and applied with a low viscosity adhesive to areas requiring support before treatment. Image: *The Clifford Aurora*, Castle Amerongen, Image Source: Kate Seymour, SRAL.

Here, a facing has been applied to the entire painting. Image: Anonymous, *Madonna and Dominican Monk*, Image Source: Kate Seymour, SRAL.

it is possible to dampen the tissue lightly (for example with a mister) before it is applied to the surface and the adhesive is applied through the tissue.

Weak, viscous, non-penetrating adhesives can be used for temporary facings, while consolidation of flaking paint through a thin piece of tissue should be done with a thin, strong, low viscosity, penetrating adhesive. Typical adhesives used for applying facings are cellulose ethers, weak solutions of gelatine or sturgeon glue. Prior to attaching a facing, the plan for its removal should be in place.

Note that aqueous adhesive solutions can be applied as a film to facings in the studio and reactivated in-situ with water. This avoids having to take adhesive mixtures on site.

Consolidation techniques

It is important to realise the desired function of the consolidant prior to selection – should the consolidant act as an adhesive re-adhering two adherends or replenish a degraded binding medium system. Once an adhesive and solvent system has been chosen, the adhesive must be applied so that it penetrates through to the delaminated area beneath the flaking paint or between the flaking layers, or penetrates between the particles of paint.

The capillary action of the liquid adhesive will draw the adhesive into the paint structure. Pre-wetting the area that requires consolidation with solvents such as water, ethanol or a water-ethanol mix can help reduce the surface tension and therefore improve the adhesive flow and penetration of the adhesive into the required area. Other wetting agents include ox-gall, and synthetic detergents such as Agepon. These must be used in low concentrations so as to not negatively affect the strength of the adhesive.

Other methods to aid the penetration of the adhesive include warming the adhesive to reduce its viscosity, and therefore aid the flow of it. Note that the temperature must not be too high, as heat can also adversely affect the paint layers, and when combined with moisture can result in blanching of the paint film. Animal glues can be warmed to ca. 55-65°C, during preparation, but during use should be kept to around 35-45°C. to avoid compromising the adhesive strength of the glue. Accordingly, the area requiring consolidation can also be warmed to aid penetration of the adhesive. Warmed metal plates, heated sandbags, hot tables, or localised heating may be put beneath the canvas to warm the area from below, and warm lights and hot air tools can be used on the paint flakes prior to the application of the adhesive, to warm them briefly and help reform the layers (as long as these don't blow away the flakes). Warmth can also be used after the application of the consolidant by a warm spatula or tacking iron, to help lay down the flakes and aid in setting the adhesive.

Note: a good tip is to coat the metal tips of (small) hot spatulas with a silicon casting resin. These silicon-tipped heated instruments can be used directly on the surface applying heat and gentle pressure directly to the damaged area.

Using multiple applications of dilute solutions will also aid penetration of the adhesive into the desired area, and help introduce sufficient adhesive to the area.

Some paint structures will require adhesives that are relatively viscous to avoid spread or leakage to areas where adhesive is not required. Thicker adhesives will prevent the absorbent layers from wicking consolidant. Cooling the area requiring consolidation will aid in gelling animal glues upon penetration, as will adding thickening agents such as corn- or wheatstarch, or long-chained cellulose ethers such as Methocel A4M or Klucel G to adhesives.

Silicon solvents can also be used as a repellent to reduce the spread of water based consolidants to undesired areas.

Most easel paintings are consolidated while lying horizontal, face up, on a table surface. This is because gravity aids in coaxing the paint to lie down. Paintings that are fixed in place, too large to place horizontally, need emergency treatment or require only a small amount of work may be treated in other orientations. Paintings on canvas and other soft supports will require support beneath them so that they do not sag or deform during consolidation, and so that weights and tools for the consolidation treatment can be used to apply pressure to the areas required (*Diagram 7*).

Once an area of flaking or loose paint has been consolidated, the area should be placed under weight until the solvent or water has evaporated, and the flake(s) are held in place. Generally, the area is protected by a layer of tissue or non-stick silicone release paper or film and then weighted with board and a metal plate and weights. Areas of impasto can be weighted with sandbags rather than board and metal plates, as these will damage any impasto.

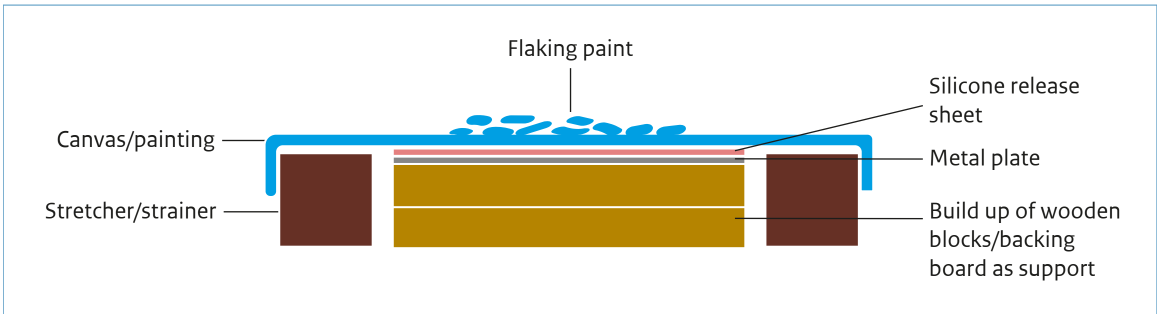


Diagram 7 showing the build-up of support under a canvas before consolidation.

Suction can also be used to help consolidate paint when the artwork must remain in a vertical position. Warmth and moisture, combined with suction, can be used to help relax flaking paint and hold it in place while the adhesive is drying. Consolidating larger areas of paint, or an entire painting, can be done successfully on a suction table. After the adhesive is applied to either the front or the reverse of the canvas, the painting is covered with a thin sheet of plastic and the suction turned on to hold the paint in place until the adhesive has set. Suction can be combined with warmth to aid the process.

A low-pressure envelop system can also be used to keep the position of any flaking paint while being treated. Air can be extracted from two plastic sheets[104] using a perforated ring attached to a motor. Windows in the upper plastic sheet can be introduced so that local sections can be treated while keeping the rest of the painting under gentle pressure. Envelopes can be constructed with the painting remaining on its secondary support.

The consolidated paint is placed under weights (here, sandbags are used) with a layer of non-stick silicone release paper to protect the area.

Consolidation of flaking paint

The consolidant or adhesive can be introduced to the area requiring consolidation by a variety of methods. If the paint flakes are not too loose or fragile, the adhesive can be applied with a fine brush, either directly under the flake or through a piece of dry Japanese tissue paper. A (micro-) syringe containing (often warmed) adhesive is also commonly used to introduce the adhesive to the area requiring consolidation. When paint is powdering or crumbling, an ultrasonic mister or other spray technique may be used to consolidate the area required (discussed further below).

Existing adhesives can also be regenerated, using solvents. Over low suction, ethanol (which has a low surface tension and good wetting abilities) can be injected with a syringe into lifted impastos and cracks and weighted with shape-conforming weights (such as small sandbags) until dry. This method can help regenerate the cohesion of paint films, without the addition of extra adhesive.[105]

Tenting paint brings its own issues, as the consolidation medium must be absorbed through the paint layer, softening it enough to lay it down without damaging the paint or leaving excess consolidant on the surface or resulting in changes to the gloss of the paint. Frequently, consolidation will need to be conducted simultaneously with treatments to humidify, tension and stretch the primary support.

Low percentages of Aquazol 50 or 200, dissolved in isopropanol, has been found in several studies to be successful in consolidating tenting paint, without damaging the paint or leaving excess gloss.[106] Warming the paint layer prior to application of the consolidation medium will help with increasing the flexibility of the paint layer, making it easier to place back down, and with the absorption of the consolidant. Pre-wetting the paint layer with water or a water-solvent mixture (such as water-ethanol) will also help subsequent absorption of the consolidant.

[104] Thin High Density Poly Ethylene plastic is preferred as this will conform to surface topographies. It is not recommended to use Melinex as this is too stiff and static.

[105] De Ségogne, H., *Théorème de Gödel by Georges Mathieu, 1957. Study and Restoration: Consolidation through cohesive regeneration using a solvent*, 2014, in: *Issues in Contemporary Oil Paint*, pp 149-157

[106] 2.5% Aquazol 200 was dissolved in 2-propanol and applied with a brush to the tenting paint. Warmth from a hot air pen was used to help absorption into the paint layer. After a few seconds the paint was gently pressed down with a warm spatula (ca. 55 °C) through a piece of silicone release paper. Mauny-van den Burg, J.M, Veerman A., van den Berg K.J., (2015) pp 190-191.

The adhesive can be applied with a small brush to the area of loss.

Consolidation of powdering/crumbling paint

The consolidation of powdering and crumbling paint must generally be treated by nebulising, misting or spraying the adhesive or consolidant. Generally, very low concentrations of consolidant are applied in multiple applications, rather than the application of a higher concentration in one sitting, to avoid excess gloss, uneven gloss and tidelines. Low concentrations (less than 1%) are also necessary to prevent clogging up the nozzle of an ultrasonic mister or spray gun. (Jun)Funori and the short-to-medium-length chain Aquazols (50 and 200) have been found to be suitable consolidants for powdering and crumbling paint, along with very low concentrations of Paraloid B72, and have the adhesive strength to bond the paint particles together, without changing the gloss of the paint layer.[107] (Jun)Funori has been found to be particularly useful for the consolidation of powdering and crumbling paint, also in combination with surface dirt removal of these otherwise difficult to treat surfaces. A 0.5-1.0 % concentration of (Jun)Funori in water, applied through a piece of wet-strength Japanese tissue will consolidate powdering and flaking matte paint, while simultaneously removing surface dirt through absorption into the tissue.[108]

[107] Ebert, B., Singer, B., Grimaldi N., 2012, Aquazol as a consolidant for matte paint on Vietnamese paintings, *Journal of the Institute of Conservation*, 35 (1) pp 62-76
Becker, K.L.M., 2014. Treating friable matte pigments on bark: experimental analysis of four consolidants, *in Journal for the Institute of Conservation*, 37(2): 152-165
Further recipes and discussion on Aquazol as a consolidant for matte and powdery paint can be found in: Arslanoglu J., 2004. Aquazol as used in conservation practice, in *WAAC Newsletter* 26 (1) pp 10-15 *http://cool.conservation-us.org/waac/wn/wn26/wn26-1/wn26-105.pdf*

[108] Mauny-van den Burg, J.M, Veerman A., van den Berg K.J., Trials and Tests for the Consolidation of Matte, Powdery Paints. Two Case Studies., 2016, in: *Colore e Conservazione, 13–14 November 2015, Politecnico di Milano. Padova*, pp 185-193
Michel, F., 2011, Funori and JunFunori: Two related consolidant with surprising properties, in *Canadian Conservation Institute Symposium Ottawa*, pp 1-14

Case Studies

Consolidation of (loose) paint flakes
Warm air pen
Water with ox-gall (to pre-wet area)
Sturgeon glue (1.5 % dissolved in water and warmed au-bain-marie)
Japanese tissue
Small weight
Small brush
Other assorted hand tools

Use the warm air pen to heat the area and increase the flexibility of the paint (and ground) flakes. The hot air pen should be set to around 55°C with a low fan speed to avoid blowing away any of the flakes. When the paint is soft and malleable, a couple of drops of water with ox-gall dissolved into it are applied along any cracks and under the flakes where possible, to help pre-wet the area and aid the movement of the consolidant under the paint flakes. Apply 1-2 drops of sturgeon glue (ca.1-3% concentration) into the cracks and under the flakes.
Keep the hot air pen directed at the paint flakes during the application of the pre-wetting agent and consolidant to maintain the flexibility of the paint (and ground) flakes. When the glue has been applied and has flowed to the areas of where it is required, gently push down the paint flakes into position with an appropriate hand tool. A silicon rubber coated dental probe or wooden stick can be very useful for this action. Remove excess glue gently with a small, slightly moist, swab, followed by a dry one. Once the excess glue has been removed, place a piece of silicon coated [baking] paper and a small weight on the area, to allow the glue to set with the flakes held in place.

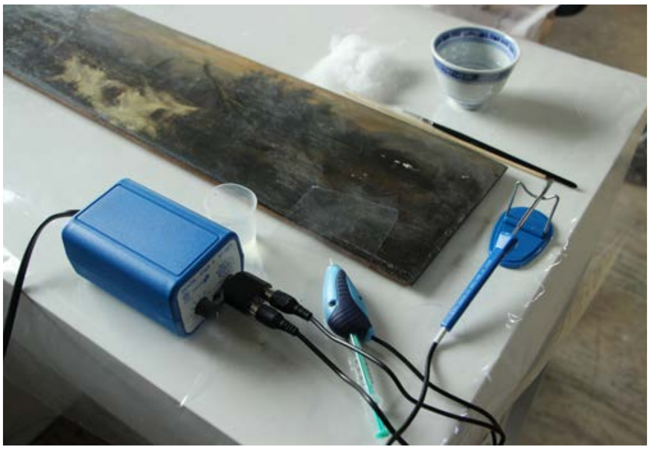
An alternative method for consolidation using a hot spatula:
Hot spatula with a small spatula head
Water with ox-gall (to pre-wet area)
Sturgeon glue (1.5 % dissolved in water and warmed au-bain-marie)
Small weight
Small brush
Other assorted hand tools

Warm the consolidant mixture to around 35°C. Allow the hot spatula to heat up to around 65°C. Place a couple of drops of water with ox-gall on the area requiring consolidation with a small brush. Manoeuvre this around to aid the flow of the water and ox-gall under the paint flakes and into the paint cracks. Leave this for a few minutes to allow the water to evaporate. With a small brush (or another method, such as a syringe) place a couple of drops/a small amount of consolidant mixture to the area requiring consolidation. When the glue has been applied and has flowed to the areas of where it is required (if necessary aided by a small brush), gently push down the paint flakes into position with the small heated spatula head, through a piece of Melinex or other silicone-release plastic film until the flake is laid down and secured. Remove excess glue gently with a small, slightly moist, swab, followed by a dry one. Once the excess glue has been removed, place a piece of silicone-coated [baking] paper and a small weight on the area, to allow the glue to cool and set with the flakes held in place.

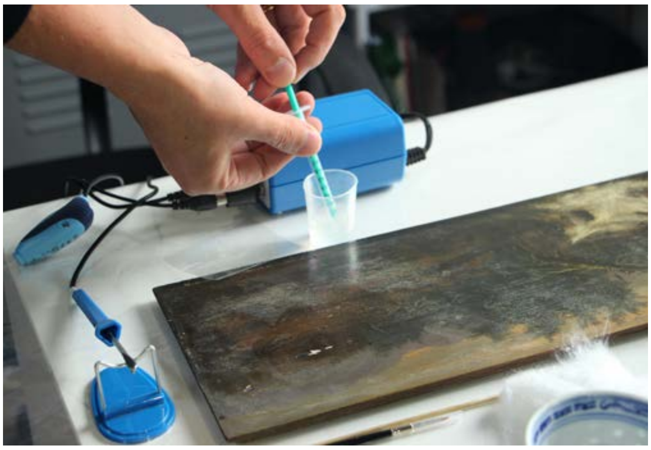
Consolidation of Powdering (and flaking) Paint[109]
Warm air pen (or hairdryer, set to a low temperature and speed)
Ultrasonic mister (medical nebuliser)
0.125 % JunFunori dissolved in water
Wet-strength (Japanese) tissue, torn into small squares
Small brush
1.0 % JunFunori, dissolved in water
Method for warming the consolidants (au-bain-marie)
Assorted hand tools

Warm the consolidant mixtures au-bain-marie to around 30-35°C (this will decrease the viscosity and aid flow of the pre-wetting consolidant into the paint layer).
Warm the area requiring consolidation with the warm air pen. Put the low-concentration JunFunori (0.125%) mixture in the ultrasonic mister and mist the area requiring consolidation for approximately 5 minutes. Ideally, the painting should be in an upright (vertical) position. Place a piece of wet-strength tissue on the surface of the painting and apply the 1.0% strength consolidant with a brush through the tissue. Leave for a few seconds, then remove the tissue carefully while it is still wet (this may be done with tweezers or other small hand tool). Apply the next tissue, slightly overlapping the area that has just been consolidated, to the painting and repeat the application of the 1.0% consolidant as above. Continue until the area is consolidated.

[109] Mauny-van den Burg, J.M, Veerman A., van den Berg K.J., Trials and Tests for the Consolidation of Matte, Powdery Paints. Two Case Studies., 2016, in: *Colore e Conservazione, 13–14 November 2015, Politecnico di Milano. Padova*, pp 185-193

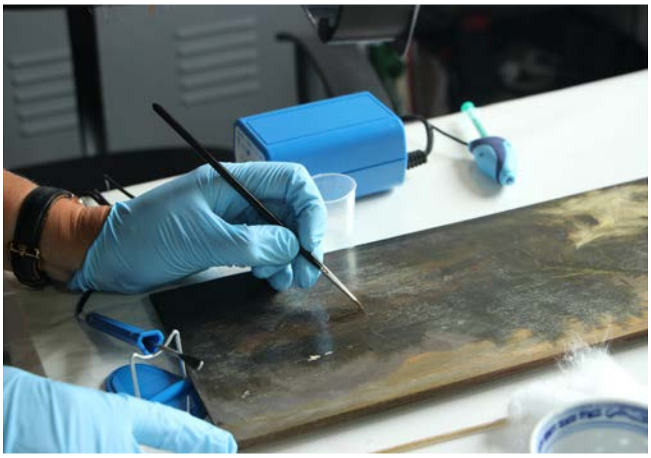


The set up and equipment for consolidating paint flakes on a panel painting.

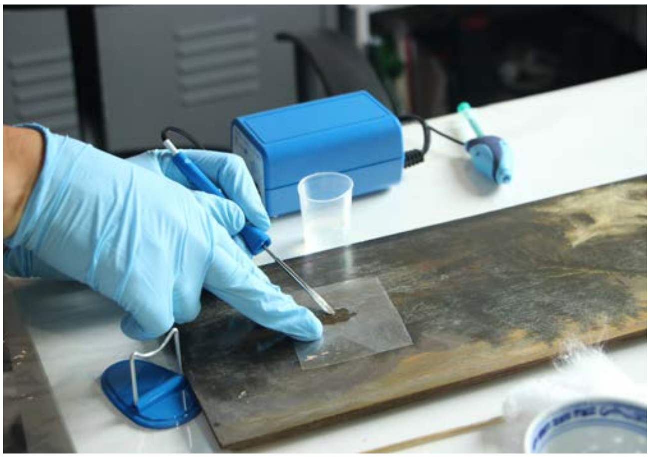


A small amount of consolidant is taken up into the syringe, which has been designed to warm the glue to a set temperature.

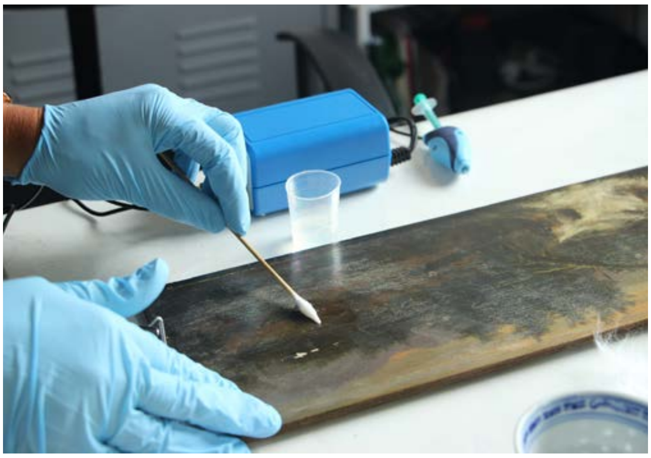
A drop of (warmed) consolidant is applied to the area with flaking/loose paint.



With a fine brush, the glue is moved around the area to aid penetration beneath the flakes.



The flaking/loose paint is laid down with a hot spatula, through a piece of non-stick silicone release sheet.



Excess glue is removed from the surface using a damp swab.

Consolidation of a painting using BEVA 371

Non-aqueous adhesives such as diluted BEVA 371 can be brushed locally to consolidate flaking or crumbling paint, or across the entire front and back surfaces of a canvas.[110]

Note that consolidation of an entire painting should only be done as a last resort, when all other methods of consolidation have been deemed unsuitable!

BEVA 371 (Gustav Berger's Original Formula)
Aliphatic hydrocarbon/ White Spirits (17% aromatic content)
Wide brush
Jars/pots/bowls with wide openings
Tyvek or other breathable, non-pilling fabric
Hot table with suction function
Strips of fabric
Melinex/silicone-release plastic film
Small thermometer strips

Mix 50 mL BEVA 371 with 150 mL White Spirits in a jar. Cover the jar and warm au-bain-marie until the mixture is clear and liquid. This will make a solution of approximately 10% concentration of BEVA 371 in solvents. In another jar, mix 50 mL BEVA 371 with 100 mL white spirits. Over the jar and warm au-bain-marie until the mixture is clear and liquid. This will make a solution of approximately 20% concentration. With a wide, flat brush, apply first the 10% concentration solution to the surface of the painting. Allow to off-gas. With a wide flat brush, apply the 20% concentration solution to the surface of the painting and allow this to also off-gas.

If the canvas is not already removed from the stretcher/ strainer, remove the canvas. Carefully place the canvas face-down on a sheet of Tyvek and apply first the 10% concentration then the 20% concentration of BEVA 371 solution to the back of the canvas. Allow to off-gas. Place the painting face-up on the hot table. Place strips of fabric along the edges of the painting, to allow for the removal of air. Place a sheet of Melinex or other silicone-release plastic over the entire painting. Place several (3-4) small thermometer strips on and around the painting. Close the lid of the table (to create the seal for the suction). Heat the table to 65°C (the table may need to be set to higher- 70°C, but the reading on the small thermometer strips should be at 65°C- this is the actual temperature of the painting). Turn on the suction to lay down the paint layer and consolidate it.[111] An extra blanket may be required on the surface to help keep the warmth on the painting during this process, and to allow the painting to reach the right temperature. After the suction and the warmth have allowed the paint to be consolidated (a few minutes), the suction and the heat can be switched off. Apply weights such as sandbags (over the blanket) to help keep the paint in place during cooling. Leave the blanket on under the weights to allow for a slower cooling of the painting. Rapid cooling can lead to stresses and strains in the paint layers, causing further damage.

Once the painting has been flattened, remove from the table. Excess BEVA 371 can be removed from the surface of the painting with White Spirits (17%) and a swab.

BEVA 371 for facings[112]

Mix 100 mL BEVA 371 from a fresh can and 100 mL VM&P Naphtha or aliphatic hydrocarbon in container. This will make a 37% solution of solid resin in solvent. Cover the container, but do not close it, and warm it in a double boiler or au-bain-marie until the solution is clear and liquid. This is suitable to use for facings, if the paint layer is water sensitive.

BEVA 371 for consolidation of paint flakes

Mix 50 mL BEVA 371 from a fresh can with 150 mL VM&P Naphtha in a container. Warm it as above until the solution is clear and liquid. This solution can be used warm to consolidate flaking paint. Apply the solution with a small brush to the edge of the paint flake, which will draw around and under the flakes through capillary action. Cover with facing paper and press to remove any excess BEVA solution. Allow to dry for 24 hours. Cover the area with a piece of silicone release paper and press down the flakes with a warm spatula or tacking iron. Allow to cool under weights, separated from the painting with a piece of silicone release paper.

[110] The instructions that come with the adhesive recommend taking one pint of BEVA 371 solution and one pint of either naphtha, xylene, or a mixture of the two in order to make a stock solution of 37% resin to solvent, Talasonline.com: *https://www.talasonline.com/images/PDF/Instructions/beva371_solution_inst.pdf*

[111] von der Goltz, M., I. Birkenbeul, I. Horovitz, M. Blewett, and I. Dolgikh (2012) Pp 398

[112] *https://www.talasonline.com/images/PDF/Instructions/beva371_solution_inst.pdf*

Appendix

JunFunori

Time to make: 4-5 hours
To dissolve JunFunori in water it has to be warmed and stirred for several hours at a temperature of between 50 and 60°C. JunFunori in solution (1 g in 100 mL of deionised water or 1%) is a colourless, transparent, water-like odourless consolidant. A solution of 0.5-1.0% has been proven to be best for consolidation. A repeat treatment has also been shown to give better results than using a higher concentration than 1% in solution. The addition of 2% isopropanol (to the solution, so 2 ml in a 100 mL solution) guarantees a longer storage life of the JunFunori, and also acts as a biocide and surfactant to the consolidant solution.[113] In addition to its use alone, Junfunori® has been combined with sturgeon glue to make a strong, matte consolidant.[114]

Recipe for Aquazol

The Aquazol resins can be used for consolidating various types of adhesive and cohesive issues. The lower MW resins are suitable for consolidating matte and powdery paint, and the higher MW resin for cupping paint. Various concentrations of the different MW Aquazol resins can be made, for example:

2.5 % Aquazol 200 in isopropanol (suitable for matte paint)
5 % 1:1 Aquazol 50: Aquazol 200 Aquazol in isopropanol (suitable for matte paint)
20 % 1:1 Aquazol 200: Aquazol 500 in water, with a few drops of ethanol added (this can be made as a stock solution and diluted as needed)
10 % 1:1 Aquazol 200: Aquazol 500 in 1:1 water: ethanol (suitable for cupping paint)

To make 10 % 1:1 Aquazol 50: Aquazol 200 in 1:1 water: ethanol:

Ingredients:
5 g Aquazol 50
5 g Aquazol 200
50 mL water
50 mL ethanol

Method:
Weigh out the resins and put in a glass beaker or jar. Measure out the solvents and put in the jar. Put the jar or beaker on a stirrer and stir until all the resin has dissolved.

Sturgeon Glue for Consolidation[115]

Time taken to make: approximately 1 day
The following recipe provides approximate weight of the dried sturgeon bladder membrane and volume of water to make a large quantity of isinglass (1 L) that will ultimately be cast into disks, preserved and stored for future use. The w/v can be adjusted according to need.

30 g of dried sturgeon bladder will yield 1000 ml of extracted collagen liquor to be cast. Practically, it is easier to divide the operation into three portions, especially for working ease of the double boiler system as well as beaker sizes.

Alternatively, the dried discs can be bought ready made from Störleim-Manufaktur, Germany.[116] This company also produce meshes of prepared sturgeon glue that can be cut to size and inserted between larger delaminated flakes and reactivated in-situ with moisture.

YIELD
Total volume: 1 L of an approximately 3% w/v solution that will be dried into individual disks that can be rehydrated as needed.
INGREDIENTS
30 g dried sturgeon bladders (bought from Kremer Pigmente/Störleim-Manufaktur)
Deionized water

DIRECTIONS
Weigh out 30 g of the dried sturgeon bladders. Soak the dried bladder in water overnight with enough water to cover the bladder. The next day, pour off and discard the soak water. Break the softened bladders into small pieces no larger than a finger nail. Add enough water to cover the bladders (for instance 333.5 ml of deionised water), this will cover the bladder enough to surround and allow the pieces to float. Put this beaker into a larger container of water au-bain-marie or use a double boiler. Heat the water bath on a low temperature (do not exceed 28°C),

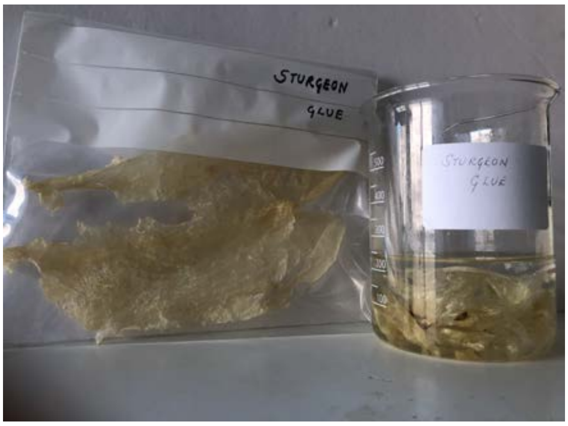
[113] Michel, F., 2011 pp 1-14
[114] Geiger, T. & Michel, F., 2005 Studies on the polysaccharide JunFunori used to consolidate matte paint, in *Studies in Conservation* 50(3) pp 193-204
[115] https://www.conservation-wiki.com/w/images/4/43/Isinglass_for_Consolidation.pdf
[116] http://www.stoerleim-manufaktur.de/

just enough to release the collagen extract from the fibre of the bladder.[117] Pay close attention to the heat, there should be no steam or bubbles released as this will in part denature the protein. The fibre of the bladder will shrink as it releases the collagen and dissolve. To keep the water from evaporating off, cover the beaker with a watch glass. After several hours, the collagen will be extracted from the fibrous membrane of the bladder. Sieve or decant this liquid through (double or triple layers) of cheesecloth or silk into a clean beaker.

Find a large undisturbed area to deposit the liquid into disks. It is important that it is a dust-free environment with enough air to flow and circulate around them during drying. Place several medium-sized sheets of silicone release (Melinex) on a flat surface where you intend to carry out dispensing of the disks. Alternatively, use silicon rubber baking trays for muffins to create the disc. Disposable pipettes or eye droppers have been found to be the best tools for distributing the liquid. Deposit and form a circular puddle of the liquid into approximately one and a half inches in diameter onto the silicon release Melinex, spaced out with enough room in between so they don't run together. The liquid should not be disturbed as it dries. This will take at least 24 hours. Alternatively, the liquid can be poured onto a sheet of Melinex or other silicone-coated release polyester sheet and cut into pieces when dry.

Once dry, the dehydrated disks can be peeled off the Melinex and stored in a glass jar. A 1-1.5% solution is generally used for consolidation purposes. Because of the ever-increasing difficulty in securing Russian sturgeon bladder, only small quantities are made as needed.
Example: to make 10 ml of a 1.5 % isinglass solution for consolidation:
Weigh 0.15 g of sturgeon glue in dry disk form (folded or torn into small pieces)
Place these pieces into a small beaker
Add 10 ml deionized water to the sturgeon glue
Create a bain-marie or water bath
Heat on a warm hot plate until disks are dissolved into solution. Excess glue can be stored in syringes in the fridge until required.
Never mix ethanol into the sturgeon glue as this will denature or dismantle the structure.

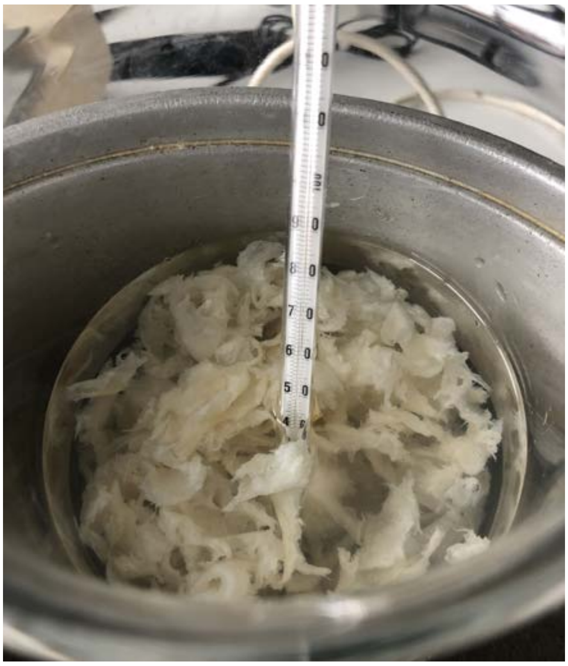
The equipment required to make sturgeon glue. Images in this series are courtesy of Kate Seymour



Take around 30 g of the glue, cover with water and soak overnight.

bladder into pieces no larger than a fingernail and put into a beaker.

[117] It is important to maintain the triple helical structure of the collagen for effective working properties. Thermal denaturation of isinglass occurs at 29°C.



Add around 330 mL of water and put the beaker into a pan with water, to warm au-bain-marie.

Heat the water bath, but do not allow the sturgeon glue and water mixture to exceed 28°C. After several hours, the collagen will be extracted from the membrane.

Sieve or decant this liquid through (double or triple layers) of cheesecloth or silk into a clean beaker.

Place several sheets of silicone-release sheets on a flat surface.

Pour the liquid onto the silicone-release (Melinex) sheet.

Allow the sturgeon glue to dry. This will take at least 24 hours.

Extra sturgeon glue (1-3 % dissolved in water can be kept in syringes in the fridge.

Sturgeon glue can also be made into a mesh, to be re-activated when needed.

About the authors

Julia van den Burg

Julia van den Burg is a freelance paintings conservator who works in the Netherlands. She graduated from the University of Amsterdam in 2013 with a post-doctoral training in Conservation and Restoration, specialising in paintings. She has gained practical experience working in both the Netherlands and Australia, working on a wide variety of paintings and painted surfaces from all eras, including the ceilings of the Trippenhuis in Amsterdam and the murals of the Fremantle Prison, a UNESCO World Heritage Site. She has worked on various projects together with the Cultural Heritage Agency of the Netherlands, having also compiled the information for the Modern Paint Damage Atlas (*https://paint.tool.cultureelerfgoed.nl/info/background*).

Kate Seymour

Kate Seymour is art historian, conservator and educator. She received her MA Hons in History of Art (Aberdeen University) in 1993 and her MA in Conservation of Easel Paintings (University of Northumbria at Newcastle) in 1999, after completing a three year diploma conservation programme in Florence, Italy. She has worked at the Stichting Restauratie Atelier Limburg (SRAL), Maastricht (the Netherlands) since 1999 as a painting conservator and is currently the Head of Education at this institution. Her position entails working as part of the guest faculty at the University of Amsterdam and University of Maastricht. At the former, she supervises the practical and research work carried out by post-graduate students (paintings) following the Master of Arts Conservation and Restoration of Cultural Heritage, as well as teaching and lecturing on a variety of subjects, both academic and practical, throughout the two year Master of Science in Conservation Studies. For the latter, she also co-organises and teaches modules (FASOS and MSP) aimed at introducing conservation science, including imaging of artworks and pigment sample analysis to Liberal Arts and Science Bachelor students. Additionally, she gives workshops on conservation practice and theory to mid-career conservators internationally. Furthermore, Kate Seymour is currently chair of the ICOM-CC Directory Board (2020-2023).

Klaas Jan van den Berg

Klaas Jan van den Berg is senior scientist at the Cultural Heritage Agency of the Netherlands (RCE) and professor of Conservation Science (Painted Art) at the University of Amsterdam, Faculty of Humanities, Group of Conservation and Restoration of Cultural Heritage. He teaches organic chemistry, technical art history and other chemical aspects of painted art. His main focus is the study of formulations, techniques, material changes and surface cleaning in 20th Century oil paintings.
Klaas Jan has written or co-authored over 140 scientific publications has been supervisor of a number of students of both science and conservation background. He organised the Issues in Contemporary Oil Paint symposium in 2013, and the Conference on Modern Oil Paints in 2018, and is editor of their Proceedings (Springer Nature, 2014 and 2019). He was project leader of the HERA-JPI EU project 'Cleaning of Modern Oil Paints'. Klaas Jan is currently leading the 20th Century Cultural Heritage research programme (2021-2023) at RCE.

Lia Gorter

Lia Gorter studied at the Textil Ingenieur Schule, Künstlerische Abteilung, Krefeld, and the University of Amsterdam. She is the director of the Foundation for Cultural Inventory (SCI), Amsterdam, since 1997. SCI digitizes and documents Dutch and Flemish cultural heritage in seldom known museum collections in non-western countries. SCI organizes exhibitions; publishes books and organizes international Masterclasses on preservation and conservation of paintings. The Masterclasses SCI organizes in co-operation with SRAL, the Conservation Institute and the Cultural Heritage Agency of the Netherlands. The SCI works in Russia in the Tretyakov Gallery, Moscow; Siberia with ten Siberian Museums in the Vrubel Museum in Omsk and in Mumbai, India in the Chhatrapati Shivaji Maharaj Vastu Sangrahalaya, CSMVS, the former Prince of Wales Museum.

This is one of a series of six brochures describing various aspects of conservation practice of works of painted art:
The brochures are intended for practicing conservators as well as other professionals involved in the field of painted cultural heritage.

The Cultural Heritage Agency of the Netherlands provides knowledge and advice to give the future a past.