Hans Hofmann's Last Lesson: A Study of the Artist's Materials in the Last Decade of His Career

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Abstract This paper summarises the analysis of more than 500 paint and fibre samples from the late-career work of Abstract Expressionist painter and teacher Hans Hofmann (1880–1966) and finds a correlation between condition issues in Hofmann's work and the combination of new paint materials with traditional art practice. The results of this study help to inform the conservation of Abstract Expressionist and other works that incorporate both traditional and modern paint media.

Keywords Hofmann • Abstract Expressionism • Modern art conservation • Modern materials • Painting technique

Introduction

> You cannot help it. You belong to a certain time. You are yourself the result of this time. You are also the creator of this time. (Hans Hofmann 1966)[1]

The late-career work of renowned Abstract Expressionist painter and teacher Hans Hofmann (1880–1966) shows us why and how we need to change our thinking about the conservation of modern art. The use of new art-making materials and processes is one of the great legacies of Abstract Expressionism, but the notion that twentieth-century modernist innovators wholly abandoned traditional painting practice is a myth that sometimes compromises the approach to conservation of these works. A mixture of old and new methods and media is more representative of period art-making. Many of the problems encountered by conservators in the treatment of modern paintings are directly related to the mixture of familiar

[1] Jaffe (1971), 37.

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Fig. 1 Hans Hofmann at work in his studio, 1952/Kay Bell Reynal, photographer (Photographs of artists taken by Kay Bell Reynal), Archives of American Art, Smithsonian Institution

techniques and new paint formulations used by Hofmann and other Abstract Expressionists. The study of Hofmann's palette is an appropriate and informative addition to the research canon. Understanding the transitions in painting practice during this period has ramifications for the future conservation treatment of Abstract Expressionist and later works that incorporate both traditional and modern paint media (Fig. 1).

This paper is based on doctoral research undertaken as part of the Preservation Studies Program at the University of Delaware (USA), in which a representative catalogue of Hofmann's late-career materials was built from the analysis of over 500 paint and fibre samples. The research aimed to assess relationships between Hofmann's materials, technique, and the impact of his choices on the long-term stability of his work. The research builds on the author's earlier analysis of mid-twentieth century commercial house paints and assessment of the condition issues related to commercial paint and ground layers observed in works from the Smithsonian Institution's Hirshhorn Museum and Sculpture Garden. A range of complementary analytical techniques were used to examine 26 paintings and eight palettes chosen as exemplars of Hofmann's work from the years 1953–1965, years just prior to and after the 1958 closing of Hofmann's art schools in New York City and Provincetown, Massachusetts. The primary goal for analysis was the broad

characterisation of materials to confirm Hofmann's use of industrial materials in his ground layers and to identify Hofmann's use of newly developed pigments or paint media in his paintings.

Study Group Selection

> Hofmann is certainly one of the most uncompromising representatives of what some people call the spatter-and-daub school and I, more politely, have christened Abstract Expressionism. (Robert Coates, *The New Yorker* 1946)[2]

Artist selection. Hans Hofmann was an influential artist and teacher positioned at the center of the Abstract Expressionist community at a pivotal period of change in artistic production. His authority with practitioners and critics and his esteemed teaching role in the United States and made Hofmann simultaneously the influencer and the benefactor of the leading edge of modern art practice. Hofmann studied in Munich and Paris during formative modernist periods and his influence both in Europe and the USA was significant. Hofmann's paintings are a synthesis of Abstract Expressionist style, material constructions that symbolise the changing relationship between artists and art-making. "Hofmann's powerful handling . . . called attention to the physical nature of the paint matter," recalled *New York Times* critic and former Museum of Modern Art curator Sam Hunter, "and thus propelled it forward." (Yohe 2002, 30) The study of Hofmann's late-career paintings provides insight into not only the style but also the substance of the era's artistic and material innovation. "Hofmann's art," Hunter noted, "is surely one of the remarkable examples in the century of modern artistic style of consciousness reporting objectively on itself." (Yohe 2002, 31)

Painting selection. The bulk of the paintings studied were selected from the Hofmann collection at the University of California Berkeley Art Museum and Pacific Film Archive (Berkeley, California), the world's largest and most comprehensive public collection of the artist's work, with additions from the Albright-Knox Art Gallery (Buffalo, New York), the Memorial Art Gallery (Rochester, New York) and the Museum of Modern Art (New York, New York). Palettes were selected from the holdings of the Renate, Hans and Maria Hofmann Trust (New York, New York). Twenty-six paintings and eight palettes were chosen for study and analysis as exemplars of Hofmann's late-career work. The study group includes 23 works on canvas from the years 1953–1965. Two works on canvas from the late 1940s were included for comparison, as were eight palettes on various supports found in Hofmann's studio at the time of his death. Paintings on panel were not included. The paintings selected for this study represent the range of Hofmann's late-career materials and paint application methods. Table 1 presents a chronological listing of the study group paintings.

[2]Coates (1946), 83.

Table 1 Chronological listing of Hofmann paintings selected for study group

Year	Title	Collection	Acc. no.	Size
1947	*Delight*	MoMA	2.1956	50.0 × 40.0″ (126.9 × 101.6 cm)
	Ecstasy	BAM	1963.2	68.0 × 60.0″ (172.7 × 152.4 cm)
	The Third Hand	BAM	1966.48	60.1 × 40.0″ (152.7 × 101.6 cm)
1953	*Le Gilotin*	BAM	1965.15	58.0 × 48.0″ (147.3 × 121.9 cm)
1954	*Scintillating Space*	BAM	1966.47	84.1 × 48.4″ (213.6 × 122.9 cm)
1955	*Exuberance*	AKAG	1955:8	50.0 × 40.0″ (127.0 × 101.6 cm)
1957	*Sommernachtstraum*	AKAG	1958:4	52.0 × 60.0″ (132.1 × 152.4 cm)
1958	*Equinox*	BAM	1965.12	72.1 × 60.3″ (127.0 × 101.6 cm)
	Morning Mist	BAM	1966.45	55.1 × 40.4″ (140.0 × 102.6 cm)
1959	*Above Deep Waters*	BAM	1965.13	84.2 × 52.0″ (213.9 × 132.1 cm)
	Indian Summer	BAM	1965.11	60.1 × 72.2″ (152.7 × 183.4 cm)
	Ruby Gold	MAG	60.37	55.4 × 40.5″ (140.7 × 102.9 cm)
	The Vanquished	BAM	1966.49	36.1 × 48.1″ (91.7 × 122.2 cm)
1960	*Bald Eagle*	BAM	1964.3	60.3 × 52.3″ (153.2 × 132.8 cm)
	In the Wake of the Hurricane	BAM	1965.6	74.3 × 60.0″ (153.2 × 132.8 cm)
1961	*Combinable Wall I and II*	BAM	1963.10	84.5 × 112.5″ (214.6 × 285.8 cm)
	Tormented Bull	BAM	1963.6	60.1 × 84.3″ (152.7 × 214.1 cm)
1962	*Heraldic Call*	BAM	1965.17	60.3 × 48.4″ (153.2 × 122.9 cm)
	Magnum Opus	BAM	1963.7	84.1 × 78.1″ (213.6 × 198.4 cm)
	Memoria in Aeternum	MoMA	399.1963	84.0 × 72.1″ (213.4 × 183.2 cm)
1963	*Polyhymnia*	BAM	1964.1	72.1 × 60.3″ (183.1 × 153.2 cm)
1964	*The Clash*	BAM	1965.8	52.1 × 60.3″ (132.3 × 153.2 cm)
	Imperium in Imperio	BAM	1966.43	84.1 × 52.0″ (213.6 × 132.1 cm)
	And Out of the Caves the Night Threw a Handful of Pale Tumbling Pigeons in the Light	BAM	1965.4	84.1 × 60.3″ (213.6 × 153.2 cm)
	Silent Night	BAM	1965.5	84.0 × 78.3″ (213.4 × 198.9 cm)
1965	*Struwel Peter*	BAM	1966.5	72.1 × 60.3″ (183.1 × 153.2 cm)
1966	Palette on plywood	Estate	M536-12	7.5 × 7.5″ (19.1 × 19.1 cm)
	Palette on board	Estate	M593-12	4.8 × 9.0″ (12.1 × 22.9 cm)
	Palette on board	Estate	M537-10	41.0 × 8.0″ (104.1 × 20.3 cm)
	Palette on board	Estate	M536-53	6.5 × 8.0″ (16.5 × 20.3 cm)
	Palette on glass	Estate	no #	24.0 × 24.0″ (61.0 × 61.0 cm)
	Palette on paint can lid	Estate	M536-49	6.0″ (15.2 cm) diameter
	Palette on board	Estate	M536-45	6.0 × 11.8″ (15.2 × 29.8 cm)
	Palette on board	Estate	M536-03	4.0 × 11.0″ (10.2 × 27.9 cm)

KAG Albright-Knox Art Gallery (Buffalo, New York), *BAM* University of California Berkeley rt Museum and Pacific Film Archive (Berkeley, California), *Estate* Renate, Hans and Maria ofmann Trust (New York, New York), *MAG* Memorial Art Gallery, University of Rochester Rochester, New York)

Primary sources of information related to the paintings included the conservation records of the Berkeley collection held at the Berkeley Art Museum and the San Francisco Museum of Modern Art. The conservation staff at the San Francisco Museum of Modern Art have been responsible for the preservation of the university's Hofmann paintings since 1974 and maintain an archive recording nearly 40 years of conservation assessment and treatment for the collection. The Berkeley Art Museum also maintains a curatorial archive related to the collection's conservation. Two unpublished surveys of the Berkeley Art Museum's Hofmann paintings produced by conservators Thornton Rockwell (1982) and Carolyn Tallent (1988) were also consulted.

Analysis of Materials

A total of 284 paint material and 28 fibre samples were taken from the study group paintings and palettes. Some paint samples presented multilayered stratigraphy and were mounted as cross-sections to allow each paint layer to be analysed separately. A total of 519 discrete paints were analysed for this research. Information regarding ground layer stratigraphy and identification of inorganic pigments was obtained using optical microscopy and scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDX). Fourier transform infrared spectroscopy (FTIR) and gas chromatography-mass spectrometry (GCMS) were used to identify binders and organic pigments.[3] The sample preparation methods and instruments used are listed in the appendix. The results of each analytical method are discussed below in order of application.

Optical Microscopy. Optical microscopy was primarily utilised for initial examination and photo-documentation of the study group samples. All 284 paint material samples and 28 fibre samples were examined and photographed using both normal and ultraviolet illumination sources. 83 of the 284 paint samples presented multilayered stratigraphy and were selected for mounting and analysis as cross-sections.

Examination of warp and weft fibres from the study group paintings indicates a distinct late-career shift in Hofmann's choice of fabric support. Cotton canvases were identified on two 1947 paintings from which fibre samples were available, while linen fibres were identified in the canvases from all 14 of the late-career paintings from which fibre samples were available.

Pyrolysis-Gas Chromatography-Mass Spectrometry. GCMS analysis was utilised in order to differentiate between modern and traditional binding media in Hofmann's materials. GCMS binding media analysis was performed on 106 samples. A pyrolysis (Py) attachment was used for all GCMS analysis, to meet the

[3] Analysis conducted by the author at the scientific laboratories of the National Gallery of Art, Washington and the Museum Conservation Institute, Smithsonian Institution.

thermal dissociation requirements of the high molecular weight and heavily cross-linked polymers found in modern paints such as alkyds and modern industrial blends that contain alkyd or acrylic modifiers. Py-GCMS analysis was used where materials were expected to contain modern polymer formulations, such as ground layer paints suspected to contain house paints (Rogala et al. 2010) and those paints exhibiting the flow characteristics or surface sheen associated with industrial paints (Tallent 1988; Arslanoglu et al. 2013). All white and black paints were analyzed using Py-GCMS in order to observe any patterns in use between ground and compositional painting materials. Selected coloured paints were also included in Py-GCMS analysis.

Py-GCMS analysis of Hofmann's paint materials confirmed Hofmann's preferential use of oil-based paint materials and his late-career shift to oil-based alkyd paints in his ground and priming layers. Py-GCMS chromatograms of all 106 samples contained peaks consistent with the palmitic, stearic, oleic, and azelaic fatty acids in oil paint. All three paintings produced in 1947 gave positive results for oil grounds using Py-GCMS analysis. All 17 of the late-career paintings from which ground layer samples were available also included peaks consistent with the phthalic anhydride component of alkyd paints.[4] Py-GCMS analysis was not possible on the limited ground layer sample from the 1960 painting *Bald Eagle*, but SEM-EDX results showing a bulked titanium white layer are consistent with the SEM-EDX results for the alkyd white grounds found in the other paintings, suggesting that a similar ground was used.[5] Alkyd grounds were also found on two primed palettes from Hofmann's studio. Paint under the lip of an impromptu palette made from a paint can lid was also found to be alkyd paint, and the embossed markings on the can lid were traced to a batch of alkyd interior house paint produced on March 17, 1957 by Benjamin Moore & Company. Brochures for this paint were found among Hofmann's studio papers (Rogala 2005). Table 2 presents a summary of all binding media identified during analysis of Hofmann's late-career ground and priming layer materials.

Black paints in alkyd binding media were also found in *Bald Eagle, Tormented Bull*, and *Heraldic Call*. No coloured alkyd paints were identified. No acrylic or water-based paints were identified in any of the samples analyzed using Py-GCMS.

Scanning Electron Microscopy-Energy Dispersive Spectroscopy. SEM-EDX analysis was utilised to identify elements associated with inorganic pigments in Hofmann's paints. EDX was utilised as a qualitative technique to group the samples into inorganic pigment families and highlight potential organic pigments requiring additional analysis.[6] Backscatter electron images were taken of all loose and mounted paint samples, and EDX inorganic materials analysis was performed on all discernable paint layers within those samples.

[4]Tallent (1988) suggests that the oil ground layer found on *Tormented Bull* is a commercially applied ground. Hofmann's applied layer of alkyd should therefore be considered a ground layer.

[5]Hofmann used zinc white compositional paints. Zinc white makes a poor alkyd, so a zinc-lacking paint is also a good indicator of an alkyd in Hofmann's paintings.

[6]EDX analysis was also performed on visible inclusions within individual paint layers.

Table 2 Summary of ground and priming layer analysis

Year	Title	Acc. no.	Sample no.	Result	Method(s)
1947	*Delight*	MoMA 2.1956	N21	Oil	Py-GCMS
	Ecstasy	BAM 1963.2	Esc01	Oil	Py-GCMS
	The Third Hand	BAM 1966.48	C071	Oil	Py-GCMS
1954	*Scintillating Space*	BAM 1966.47	C072	Alkyd	Py-GCMS
1955	*Exuberance*	AKAG 1955:8	B03	Alkyd	Py-GCMS, ATR-FTIR
			B04	Alkyd	Py-GCMS
1957	*Sommernachtstraum*	AKAG1958:4	B17	Alkyd	Py-GCMS, ATR-FTIR
1958	*Equinox*	BAM 1965.12	C057	Alkyd	Py-GCMS
1959	*Above Deep Waters*	BAM 1965.13	C121	Alkyd	Py-GCMS, ATR-FTIR
	Ruby Gold	MAG 60.37	R07	Alkyd	Py-GCMS
			R11	Alkyd	Py-GCMS
1960	*Bald Eagle*	BAM 1964.3	C026b	Alkyd	SEM-EDX
	In the Wake...	BAM 1965.6	C180	Alkyd	Py-GCMS
1961	*Combinable Wall I/II*	BAM 1963.10	C085	Alkyd	Py-GCMS, ATR-FTIR
	Tormented Bull	BAM 1963.6	C059	Alkyd[a]	Py-GCMS
1962	*Heraldic Call*	BAM 1965.17	Hera01	Alkyd	Py-GCMS
	Magnum Opus	BAM 1963.7	C151	Alkyd	Py-GCMS, ATR-FTIR
			C153	Alkyd	Py-GCMS, μFTIR
	Memoria in Aeternum	MoMA 399.1963	N04	Alkyd	Py-GCMS, ATR-FTIR
1963	*Polyhymnia*	BAM 1964.1	C137	Alkyd	Py-GCMS, ATR-FTIR
1964	*The Clash*	BAM 1965.8	C003	Alkyd	Py-GCMS, ATR-FTIR
	And Out of the Caves...	BAM 1965.4	C169	Alkyd	Py-GCMS, ATR-FTIR
	Silent Night	BAM 1965.5	C101	Alkyd	Py-GCMS, ATR-FTIR
1965	*Struwel Peter*	BAM 1966.5	C145	Alkyd	Py-GCMS, μFTIR
1966	Palette on board	Estate M536-45	S26	Alkyd	Py-GCMS, ATR-FTIR
	Palette on board	Estate M536-03	S29	Alkyd	Py-GCMS, ATR-FTIR

AKAG Albright-Knox Art Gallery (Buffalo, New York), *BAM* University of California Berkeley Art Museum and Pacific Film Archive (Berkeley, California), *Estate* Renate, Hans and Maria Hofmann Trust (New York, New York), *MAG* Memorial Art Gallery, University of Rochester (Rochester, New York), *MoMA* Museum of Modern Art (New York, New York), *Py-GCMS* Pyrolysis-Gas Chromatography-Mass Spectrometry, *SEM-EDX*: Scanning Electron Microscopy-Energy Dispersive Spectroscopy, *ATR-FTIR, μFTIR*: Attenuated Total Reflectance- and Micro-Fourier Transform Infrared Spectroscopy

White. The pigments identified in Hofmann's ground and compositional materials are consistent with reports of the artist's shift from oil- to alkyd-based ground layers. Mixed zinc and titanium white pigments (distinguishing elements: Zn, Ti) consistent with zinc oxide oil paint formulations were identified in the ground layers of all three of the study group paintings produced in 1947. No zinc pigments were identified in the ground layer materials of the 17 late-career paintings from which ground layer samples were available, but all of available late-career ground layer samples were found to contain titanium white paints consistent with alkyd white paints. All but one of the study group paintings contained compositional applications of zinc/titanium mix white paints consistent with Hofmann's reported use of Permalba (De Kooning 1950). All but one of the study palettes included similar zinc and titanium containing pigment mixtures. *Heraldic Call* contained no compositional white paints.

Yellow. Cadmium-containing yellows (distinguishing elements: Cd, S) were the primary yellow pigments found in Hofmann's late-career work. Cadmium-containing yellows appear in nearly every study group painting and palette, alone or mixed with zinc/titanium white or ultramarine blue.[7] Yellow ochre (distinguishing element: Fe) appears infrequently throughout the study group. Cadmium yellow and yellow ochre both appear in the 1947 painting *Delight*, in *Sommernachtstraum* (1957), *Morning Mist*, (1958) *Combinable Wall I and II* (1961) *Silent Night* (1964), and the unnumbered Estate palette on glass. In *Combinable Wall I and II* a secondary shade of cadmium yellow included a calcium-based extender. In *Imperium in Imperio* a secondary shade of cadmium yellow included a barium-based extender.[8] Zinc chromate yellow (distinguished by the presence of Zn and Cr) appears twice in the study group. Cadmium yellow and zinc yellow both appear in *Ecstasy* (1947) and *Equinox* (1958).

Orange. Cadmium-containing orange (distinguishing elements: Cd, S, Se) is the only orange pigment identified in the study group samples. Cadmium orange appears consistently in the paintings and palettes from 1954, occasionally mixed with zinc/titanium white. *Ruby Gold* (1959) included a secondary shade of cadmium orange mixed with a calcium-based extender and *Combinable Wall I and II* (1961) included a secondary shade of cadmium orange mixed with a barium-based extender.

Red. Cadmium-based red (distinguishing elements: Cd, S, Se) appears consistently throughout the study group paintings and palettes, sometimes mixed with zinc/titanium white, and regularly in compositions containing a range of other cadmium-based colours. A barium-based extender was mixed with secondary shades of cadmium red in *Above Deep Waters* and *Indian Summer* (both 1959), and in one of the palettes (Estate M536-53). Supplemental reds in *Combinable Wall I and II* (1961) were mixed with zinc/titanium white or with the titanium white ground material. Cadmium red and an oxide red-brown both appear in *Sommernachtstraum* (1957).

Green. A variety of green pigments were identified in the paintings, including artist's mixtures of cadmium yellow and ultramarine blue. A more homogenous green containing components of cadmium green (elements: Cd, Zn, S) appears consistently in the paintings and palettes beginning in 1953. The cadmium-containing green often appears on the same composition as phthalocyanine green (distinguishing elements: Cl, Cu), and may be the phthalocyanine-containing "[permanent] green light" that appears on a pigment list found among the artist's papers.[9] The cadmium-containing green appears alone on the 1955 painting *Exuberance*, *Sommernachtstraum* (1957) *Morning Mist* (1958) *Memoria in Aeternum* (1962) and *Polyhymnia* (1963). Phthalocyanine green appears alone on the 1947 paintings *Ecstasy* and *The Third Hand*, and on *The Clash* (1964). A second cadmium-containing green in *Above Deep Waters* (1959) is mixed with a barium extender. Viridian, also known as chrome green (distinguishing element: Cr) appears infrequently; a chrome-based green was found alone in samples from *Delight* (1947) and together with cadmium and phthalocyanine greens in *Silent Night* (1964). Similarly, a greenish iron oxide pigment (distinguishing element: Fe) appears infrequently; together with cadmium green in *Ruby Gold* (1959) and with cadmium and phthalocyanine greens in *And Out of the Caves the Night Threw a Handful of Pale Tumbling Pigeons in the Light* (1964). A possible cobalt green (distinguishing elements: Co, Zn) appears with cadmium green in *Memoria in Aeternum* (1962) and with cadmium, phthalocyanine, and chrome greens in *Silent Night*.

Blue. Ultramarine blue (distinguishing elements: Na, Al, Si) is the primary blue pigment appearing in Hofmann's late-career work. Ultramarine blue pigment appears in every painting except the black-and-white composition *Tormented Bull* (1961). Ultramarine blue appears alone and mixed with a variety of colours. Phthalocyanine blue (distinguishing element: Cu) appears with ultramarine blue in the 1947 painting *Ecstasy*, and on *Le Gilotin* (1953) and *Morning Mist* (1958). Phthalocyanine blue also appears on the unnumbered glass palette. Cobalt blue (distinguishing elements: Co, Al) was used in four paintings from the 1960s: *Bald Eagle* (1960), *Magnum Opus* (1962), and *Imperium in Imperio* and *Silent Night* (both 1964). Cerulean blue (distinguishing elements: Co, Sn) appears in only one painting, *Equinox* (1958). An iron-containing blue (possibly Prussian Blue) appears in one painting, *Sommernachtstraum* (1957), and one of the palettes (Estate M536-45).

Violet/Magenta/Purple. Both inorganic and organic purple pigments appear in Hofmann's paintings. Cobalt violet (distinguishing elements: Co, P) was found in many of his later paintings, from *Le Gilotin* (1953) to *Struwel Peter* (1965).

Sampling from palettes was limited to priming layers colours used for mixing. Other colours in consistent late-career use may also appear on the palettes.

Precise identification of extenders would require further analysis.

[9] Phthalocyanine pigments contain both organic and inorganic components and can therefore be identified using multiple analytical techniques—in the case of this study, by both FTIR and SEM-EDX.

A similar violet pigment with inconclusive EDX spectra but exhibiting similar topographical characteristics in SEM and closely similar FTIR spectra was found in *Ruby Gold* and *Indian Summer* (both 1959), *In the Wake of the Hurricane* (1960), and *And Out of the Caves the Night Threw a Handful of Pale Tumbling Pigeons in the Light* (1964) Ultramarine violet (distinguishing elements: Na, Al, S) was found in one painting *Morning Mist* (1958). EDX analysis of magenta paint samples from 12 of the 23 study group paintings identified levels of aluminum or barium consistent with substrate used in natural and synthetic dye-based pigments. Further information regarding these pigments was obtained through organic analysis (see FTIR analysis below).

Black. Hofmann's late-career paintings exhibit limited use of black pigment. Ivory black, also known as bone black (distinguishing elements: Ca, P) was found in samples from eight paintings, the earliest occurrence in *Ecstasy* (1947), and the last in *The Clash* (1964). Ivory black frequently appears mixed with phthalocyanine green in Hofmann's paintings. *Heraldic Call* (1962) and the previous year's *Tormented Bull* contain both oil and alkyd blacks. Neither black in *Tormented Bull* has a discernable EDX signature, thus indicating the presence of carbon black pigment. Blacks without discernable EDX signatures also appear in *Delight* (1947), *Ruby Gold* and *The Vanquished* (both 1959), and *Bald Eagle* (1960), although carbon black cannot be reliably characterised by EDX analysis and may appear in other paintings. *Bald Eagle* was painted with two black pigments and two paint mediums; ivory black in oil and carbon black in alkyd paint media.

Fourier Transform Infrared Spectroscopy. FTIR analysis was used to identify organic pigments, classes of organic materials, and functional groups indicative of some inorganic materials. FTIR analysis was performed on 172 loose paints and 76 cross-sections. The method used did not allow for layer-specific analysis of cross-section samples. Organic pigment identification was based on a comparison of study group spectra with the spectral databases of the Infrared & Raman Users Group (IRUG). Results listed below are organised according to international Colour Index (CI) classifications (The Society of Dyers and Colourists 1956, 3267). Table 4 presents a summary of the organic pigments identified in the paintings investigated.

Organic pigments, blue and green. Two phthalocyanine-based pigments were identified in the paintings.[10] CI Pigment Blue 15 was found in two paintings—*Le Gilotin* (1953) and *Morning Mist* (1958)—and two of the Estate palettes. Samples of pre-1953 phthalocyanine containing pigments were present in too low a concentration to be confirmed using FTIR although samples of phthalocyanine blue from *Ecstasy* (1947) showed an elemental profile consistent with other paints identified as phthalocyanine blue by FTIR. The designations PB15.1-15.6 noted in Table 4 reflect the related IRUG spectra for structural variations in the pigment, although structural identification of pigments was beyond the scope of the present study.

[10] Phthalocyanine pigments contain both organic and inorganic components and can therefore be identified using multiple analytical techniques—in the case of this study, by both FTIR and SEM-EDX.

Table 3 Pigments identified using Energy Dispersive Spectroscopy (continued)

Title	Acc. no.	Zinc white	Titanium white	Cadmium yellow	Yellow ochre	Zinc yellow	Cadmium orange	Cadmium red	Red ochre	Cadmium green	Phthalocyanine green	Viridian/ Chrome green	Iron oxide green	Cobalt green	Ultramarine blue	Phthalocyanine blue	Cobalt blue	Cerulean blue	Prussian blue	Ultramarine violet	Cobalt violet	Ivory black	Carbon black[b]
Delight	MoMA 2.1956	×		×	×			×					×		×								×
Ecstasy	BAM 1963.2	×		×		×		×			×				×	×						×	
The Third Hand	BAM 1966.48	×		×				×			×				×								
Le Gilotin	BAM 1965.15	×		×				×		×	×				×						×	×	
Scintillating Space	BAM 1966.47	×	×	×			×	×		×	×				×							×	
Exuberance	AKAG 1955:8	×	×	×				×							×								
Sommernachtstraum	AKAG 1958:4	×	×	×	×		×	×	×	×					×				×				
Equinox	BAM 1965.12	×		×		×	×	×		×	×				×			×					
Morning Mist	BAM 1965.45	×		×	×		×	×		×					×	×				×			
Above Deep Waters	BAM 1965.13	×	×	×			×	×		×	×				×							×	
Indian Summer	BAM 1965.11	×		×				×							×								
Ruby Gold	MAG 60.37	×	×	×				×		×			×		×						×		×
The Vanquished	BAM 1966.49	×		×			×	×		×	×				×						×		×
Bald Eagle	BAM 1964.3	×	×	×			×	×		×	×				×		×				×	×	×
In the Wake of the Hurricane	BAM 1965.6	×	×	×			×	×		×					×						×		
Combinable Wall I and II	BAM 1963.10	×	×	×	×		×	×		×	×				×							×	

Table 3 (continued)

Title	Acc. no.	Zinc white	Titanium white	Cadmium yellow	Yellow ochre	Zinc yellow	Cadmium orange	Cadmium red	Red ochre	Cadmium green	Phthalocyanine green	Viridian/ Chrome green	Iron oxide green	Cobalt green	Ultramarine blue	Phthalocyanine blue	Cobalt blue	Cerulean blue	Prussian blue	Ultramarine violet	Cobalt violet	Ivory black	Carbon black[b]
Tormented Bull	BAM 1963.6	×	×																				×
Heraldic Call[a]	BAM 1965.17		×					×														×	
Magnum Opus	BAM 1963.7	×	×	×				×							×		×						
Memoria in Aeternum	MoMA 399.1963	×	×	×			×	×		×				×	×								
Polyhymnia[a]	BAM 1964.1	×	×					×		×					×							×	
The Clash	BAM 1965.8	×	×	×			×	×			×				×						×		
Imperium in Imperio[a]	BAM 1966.43	×		×			×	×		×	×				×		×						
And Out of the Caves the Night Threw a Handful of Pale Tumbling Pigeons in the Light	BAM 1965.4	×	×		×			×		×	×		×								×		
Silent Night	BAM 1965.5	×	×	×	×		×			×	×	×		×	×		×						
Struwel Peter	BAM 1966.5	×	×	×			×	×		×					×						×		
Palette on plywood[a]	Estate M536-12	×									×												
Palette on board[a]	Estate M593-12	×									×												
Palette on board[a]	Estate M537-10	×		×			×	×		×	×				×								
Palette on board[a]	Estate M536-53	×					×	×															
Palette on glass[a]	Estate, no #	×		×	×					×					×	×							
Palette on paint can lid[a]	Estate M536-49	×	×												×								
Palette on board[a]	Estate M536-45	×	×												×				×				
Palette on board[a]	Estate M536-03		×								×												

AKAG Albright-Knox Art Gallery (Buffalo, New York), *BAM* University of California Berkeley Art Museum and Pacific Film Archive (Berkeley, California), *Estate* Renate, Hans and Maria Hofmann Trust (New York, New York), *MAG* Memorial Art Gallery, University of Rochester (Rochester, New York), *MoMA* Museum of Modern Art (New York, New York)

[a]Not all paint materials were sampled from this study group item

[b]Carbon black is not detectable using EDX and may be present along with other black pigments

Table 4 Pigments identified using Fourier-Transform Infrared Spectroscopy

Year	Title	Acc. no.	Phthalocyanine Blue	PB 15	PB 15:1	PB 15:2	PB 15:4	PB 15:6	Phthalocyanine Green	PG 7	Other[b]	Alizarin	PR 83	Other[c]	Rhodamine	PR 81
1947	*Delight*	MoMA 2.1956												×		
	Ecstasy	BAM 1963.2												×		
	The Third Hand	BAM 1966.48											×			
1953	*Le Gilotin*	BAM 1965.15		×	×					×	×		×			
1954	*Scintillating Space*	BAM 1966.47								×						
1955	*Exuberance*	AKAG 1955:8														
1957	*Sommernachtstraum*	AKAG 1958:4									×					
1958	*Equinox*	BAM 1965.12								×						
	Morning Mist	BAM 1966.45		×	×						×		×			
1959	*Above Deep Waters*	BAM 1965.13														
	Indian Summer	BAM 1965.11								×						
	Ruby Gold	MAG 60.37														
	The Vanquished	BAM 1966.49														
1960	*Bald Eagle*	BAM 1964.3														
	In the Wake of the Hurricane	BAM 1965.6														
1961	*Combinable Wall I and II*	BAM 1963.10									×					
	Tormented Bull	BAM 1963.6														
1962	*Heraldic Call*[a]	BAM 1965.17														
	Magnum Opus	BAM 1963.7												×		
	Memoria in Aeternum	MoMA 399.1963														
1963	*Polyhymnia*[a]	BAM 1964.1												×		
1964	*The Clash*	BAM 1965.8											×			
	Imperium in Imperio[a]	BAM 1966.43									×					
	And Out of the Caves the Night Threw a Handful of Pale Tumbling Pigeons in the Light	BAM 1965.4														
	Silent Night	BAM 1965.5								×						
1965	*Struwel Peter*	BAM 1966.5														
1966	Palette on plywood[a]	Estate M536-12														
	Palette on board[a]	Estate M593-12		×	×	×	×	×								
	Palette on board[a]	Estate M537-10								×						
	Palette on board[a]	Estate M536-53														×
	Palette on glass[a]	Estate, no #		×	×			×								
	Palette on paint can lid[a]	Estate M536-49														×
	Palette on board[a]	Estate M536-45														
	Palette on board[a]	Estate M536-03								×	×					×

AKAG Albright-Knox Art Gallery (Buffalo, New York); BAM: University of California Berkeley Art Museum and Pacific Film Archive (Berkeley, California), *Estate* Renate, Hans and Maria Hofmann Trust (New York, New York), *MAG* Memorial Art Gallery, University of Rochester (Rochester, New York), *MoMA*: Museum of Modern Art (New York, New York)

[a]Not all paint materials were sampled from this study group item

[b]Samples not directly identified as the pigment but matching FTIR spectra for other samples containing the pigment

[c]Matched to other samples identified as PR83 or presenting SEM-EDX results consistent with an alumina substrate

Organic materials consistent with IRUG standards for phthalocyanine-based CI Pigment Green 7 were identified in samples from ten paintings from 1953 to 1964 and two of the Estate palettes. Samples of phthalocyanine green from seven additional paintings and one additional palette were not available for FTIR analysis but had consistent SEM-EDX results to support the identification of phthalocyanine green paints on a total of 14 paintings and three palettes.

Lake pigments, alizarin. Alizarin-containing pigment is one of two magenta colours that appear in Hofmann's late-career work. FTIR analysis identified materials consistent with IRUG standards for CI Pigment Red 83 (an anthraquinone-based alizarin substitute for natural madder pigment) in samples from *Delight* and *The Third Hand* (both 1947) and three later works—*Le Gilotin* (1953), *Morning Mist* (1958), and *The Clash* (1964). Samples of magenta paints from there other paintings were too small to definitively identify the synthetic organic pigment used but provided FTIR matches to other samples identified as PR 83 or exhibited SEM-EDX results consistent with an alumina substrate. No examples of PR83 were found in the palettes.

Toners. A second magenta colour appears exclusively on Hofmann's late-career palettes. Xanthene-based rhodamine pigment CI Pigment Red 81 does not appear in the paintings but was identified in all three magenta paint samples available for testing from the Estate palettes using FTIR.

Discussion of Analyses

The analysis carried out in this study suggests that Hofmann's palette stays remarkably consistent from the late 1940s to the mid 1960s. The study group paintings employ the same colours recommended by Hofmann in his various student supply lists, including his life-long preference for zinc white (and zinc-titanium blends) over lead white (Hofmann Papers). The most significant shift in materials appears in Hofmann's late-career switch to exclusively alkyd grounds.[11] In 1960, splashed alkyd blacks appear, replacing the dripped inks and black oils of Hofmann's earlier work. Hofmann's palette is largely based on the modern colours that were favoured by the avant-garde throughout Hofmann's career. A handful of preferred colours appear in almost every painting in the study group. The cadmium reds and yellows embraced by Matisse and Fauves appear in every painting in the study group.[12] Hofmann's use of cadmium orange and synthetic phthalocyanine green is also consistent throughout this period, while his use of phthalocyanine blue appears to cease in 1958. Cobalt violet and alizarin crimson—Hofmann's purple and magenta staple colours—are also contemporary colour formulations. Cobalt violet

[11] *Heraldic Call* is the one exception to this, and it may be that the white background expanse was built over a commercially primed painting, as seen in *Tormented Bull*.

[12] Cadmium yellow is visible on *Heraldic Call*, but not sampled.

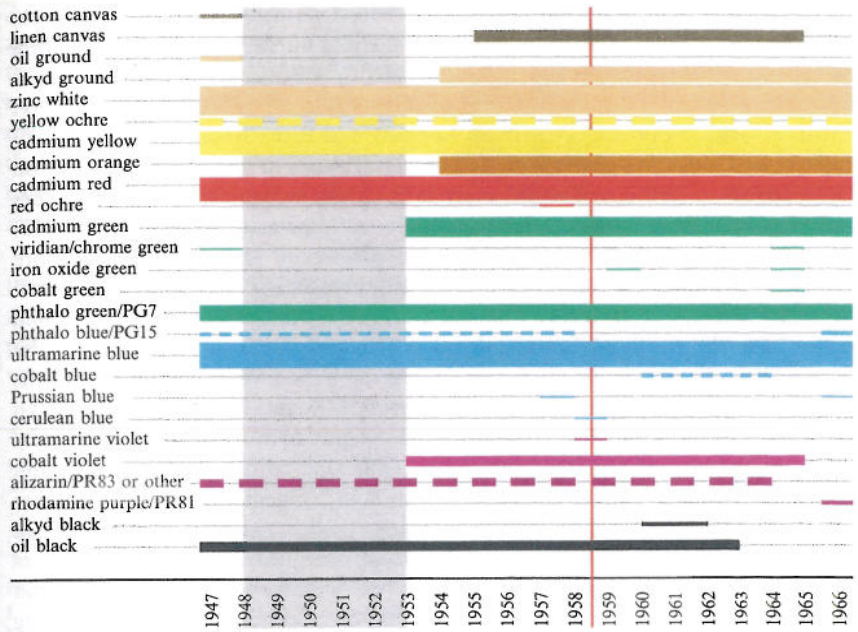

Fig. 2 Timeline of Hofmann's late-career materials. If use of a particular pigment is consistent, a solid line is drawn from beginning to end dates; sporadic use is a dashed line between beginning and end dates; the thickness of the line denotes the relative number of paintings on which the paint is found during this period. Not all colours were sampled from the study group paintings; colours not found in the study group works may exist in other paintings from the same year. *Red line* indicates the year Hofmann closed his schools and began to paint full time. No study paintings appear within grey timeframe

does not appear in the few study group paintings from the late 1940s but archival palette lists and anecdotal recollections note Hofmann's consistent use of the this colour throughout his years in the U.S. and has likely been used for other paintings made in this early period (Kiesler Papers). PR 83 is the only identifiable synthetic alizarin-based pigment used in Hofmann's paintings in the period investigated. PR 81 appears frequently but exclusively on the palettes found in Hofmann's studio at the time of his death. PR 83 was not found in any of the paintings after 1964, nor on the palettes. It is not clear whether this substitution was intentionally made by Hofmann or is the result of a formulation change by the manufacturer (Fig. 2).

Relationship of pigments and paint media to condition issues. Caretakers of Hofmann's work are faced with complex problems of lifting paint, blind cleavage, and slow-drying or efflorescing paint layers that appear to be related to Hofmann's use of new materials. Below are two examples of recurring condition issues in Hofmann's work that are not related to the paints themselves, but to Hofmann's application of new paint materials with traditional painting technique.

The alternating heavy paint layers, underbound washes, and splashed enamels f Hofmann's signature works place unusual stress on the underlying zinc white aints and house paint ground layers favored by Hofmann and his colleagues. Iofmann's mix of traditional and new paint media is representative of period ractice. Jackson Pollock, Willem de Kooning and Franz Kline, for example, all ncorporated industrial paints with traditional oil paints in their work (Coddington 999; Lake et al. 1999), and recent analysis has found industrial paint ground layers 1 works by Kline, Ellsworth Kelly, and Barnett Newman (Rogala et al. 2010; Vijnberg et al. 2011). The stiff and brittle qualities of zinc oxide oil paint are ot suited to the flexible and load-bearing requirements of Abstract Expressionist aintings (Maines et al. 2011; Osmond 2012) and works with industrial ground ayers have the potential for additional problems from ineffective house paint ormulations of zinc oxide marketed during the period when Hofmann and his olleagues experimented with house paint grounds (Rogala 2011). The white alkyd ouse paint formulations also popular with Hofmann and his Abstract Expressionist olleagues avoid the problems associated with zinc oxide pigment but exhibit imilar problematic characteristics related to high pigment volume concentration nd the brittle nature of an alkyd paint binder (Feller and Matous 1964; Hagan t al. 2007). Mechanical stresses on composite structures containing these kinds f inappropriate underlayers can result in the widespread ground failure and fting paint layers common to the work of mid-twentieth century artists including lofmann. The problem is neither the material nor the method of ground layer pplication, but the application of *this particular material* as a ground layer.

Exudates ranging from efflorescing fatty acids to expressed liquid oils are another xample of problems that arise in Hofmann's work in relation to new materials. or example, unusual drying problems have been observed in relation to synthetic ormulations of alizarin crimson (PR83) in every study group painting in which that igment appears. Hofmann painted the majority of his late-career work while at his udio in Provincetown, Massachusetts and according to Herbst and Hunger (2004, 11), the alkaline-based formulation of PR83 breaks down on exposure to common rganic solvents, such as benzine that Hofmann mixed with his paints to speed eir drying in the coastal environment (De Kooning 1950, Hofmann Papers). These eterioration issues in Hofmann's paintings may therefore not be related to the new igment formulation, but the result of incompatibility between traditional painting ractices and newly formulated painting materials. Further investigation is needed fully characterise the causes of this type of deterioration and its occurrence in aintings by other artists.

onclusion

he analysis of painting materials used for Hofmann's late-career paintings under-ken in this study highlighted the relationship between aspects of the condition of s work and his combined use of new paint materials with traditional art practices

A representative catalogue of Hofmann's materials was characterised by paint and fibre analysis and reflects Hofmann's selective adoption of modern materials throughout his career. Examples of condition issues related to Hofmann's mix of new paint materials with traditional painting technique were investigated, including the use of stiff and brittle zinc oxide-containing house paints as ground layers and the degradation of synthetic organic pigments by common nonpolar solvents. In both cases, the deterioration was caused by an unanticipated incompatibility material and method.

Hofmann's oeuvre is an example of period artistic method that has wider implications for the evaluation of conservation methodology in the treatment of Abstract Expressionist and later works that incorporate both traditional and modern paint media. The legacy of Hofmann and his Abstract Expressionist colleagues would be well served by the continued study of that era's materials and practices.

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Appendix: Experimental Conditions

Cross-sections. Samples were positioned on pre-cast epoxy half-tablets and adhered using a small droplet of cyanoacrylate adhesive. The sample and half-tablet are then transferred into a silicon rubber mold for embedding. The epoxy resin, Trabond 2113 two-part system, was mixed and poured over the adhered sample and half-tablet. The liquid resin was held at room temperature for 1 h, then cured at approximately 45 °C for 3 h. Once de-molded, the tablets were trimmed with a mill to expose the sample. Aluminum oxide abrasive was used to polish the face edge the surfaces using an aliphatic hydrocarbon as a lubricant. (Some samples were dry polished later for FTIR analysis.)

Pyrolysis-Gas Chromatography-Mass Spectrometry. Samples were analyzed using a Varian Saturn 2000 GC/MS equipped with a CDS Pyroprobe 2000. Each sample was derivatised using two microliters of tetramethylammonium hydroxide

(TMAH) put onto the sample in a quartz boat. The boat was placed into the coiled platinum probe of a CDS Pyroprobe 2000 filament pyrolysis unit, and the probe was then placed into a helium-purged CDS 1500 Valved Interface attached to the Varian GC. The interface was held at a constant 310 °C and purged with helium for 10 s before opening the valve to the GC column. The sample was then heated with the pyroprobe to a temperature of approx. 600 °C for 10 s. The pyrolysis products were transferred directly to a capillary column (ZB-5 ms; 30 m × 0.25 mm i.d.; 0.25 micron film thickness; He flow of 1.2 ml/min; splitless.) in a Varian 3800 gas chromatograph (GC) equipped with electronic flow control. The GC oven was programmed with an initial temperature of 30 °C, which was held for 5 min. The temperature was increased at a rate of 10 °C per minute to 300 °C and held for 10 min. The Varian 3800 GC was interfaced to a Varian Saturn 2000 ion trap, the transfer line being held at 270 °C. Operating conditions for the trap were: trap 150 °C, manifold at 80 °C; electron multiplier 1,500 V; scan range 45–650 amu; scan time 1 s; data analysis Saturn GC/MS Workstation 6.5 software and the NIST 2005 spectral libraries.

Scanning Electron Microscopy-Energy Dispersive Spectrometry. Samples were imaged and analyzed using a Hitachi S3700-N scanning electron microscope and a Bruker XFlash energy dispersive spectrometer with Quantax 400 software. The samples were received after they had been prepared for and imaged by polarised light microscopy. They were carbon coated before analysis. The SEM was operated at 20–25 kV, at full vacuum. Elemental maps were generated over 300 s real time (with 0–18 % dead time). Spot and area analyses were conducted for 200 s live time. Analyses were conducted at a working distance between 9.8 and 10.2 mm. EDX analysis was performed on at least three disparate points within each paint layer; inclusions were also analysed.

Fourier Transform Infrared Spectroscopy. ATR-FTIR (Attenuated Total Reflectance) analysis of loose samples was performed using a Thermo Nicolet 5700 Fourier transform infrared (FTIR) spectrometer with a Golden Gate ATR with diamond crystal, single bounce (45°) sampling accessory and DTGS detector. Spectra were obtained from 64 scans taken at a resolution of 4 cm^{-1}. Samples for ATR-FTIR were placed directly on the diamond crystal of the ATR accessory. For small samples a piece of aluminum foil was used to back the sapphire anvil to eliminate any sapphire absorption in the IR spectrum. μFTIR (Infrared Microscope) analysis of embedded cross-sections was performed using a Thermo Nicolet 6700 Fourier transform infrared spectrometer with a Continuum microscope, MCT/A detector and a single bounce diamond crystal μATR objective. Spectra were obtained from 128 scans taken at a resolution of 4 cm^{-1} between 4,000 and 525 cm^{-1}. Samples for μFTIR were examined directly using a variable aperture to choose the area of interest. All spectra were ATR corrected and examined using OMNIC v 7.2 and compared to IRUG 2000 and local spectral libraries.

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Théorème de Gödel by Georges Mathieu, 1957. Study and Restoration: Consolidation Through Cohesive Regeneration Using a Solvent

Hélène de Ségogne

Abstract This paper presents the study and restoration of Georges Mathieu's 1957 painting *Théorème de Gödel* (oil on canvas, 146 cm × 89 cm), in the Palais des Beaux Arts of Lille, France. The painting shows several signs of degradation which result from a combination of factors such as: the artist's action and painting technique: *tubisme* producing thick black impastos; the composition and interaction between the binding media, linseed oil and the ivory black pigment; the environmental conservation conditions.

Both mechanical and optical damages were identified, such as loss of cohesion and adhesion in the impastos resulting in cracks, severe cleavages and lacunas, linseed oil drips and surface soiling.

Since the painting is still not dry in the thick impastos, the deterioration is ongoing. A method was developed using little or no adhesive with the possibility of reversibility for future interventions. Pure ethanol was used to reactivate the cohesion and the adhesion of the cracked impastos.

Keywords Linseed oil • Drips • Cracks • Cleavage • Impasto • Loss of adhesion • Ivory black pigment • *Tubisme* • Ethanol

Artwork Description: Action Painting and Impastos

The artwork by Georges Mathieu, *Théorème de Gödel*, an oil on canvas painted in 1957, was presented by the Palais des Beaux Arts of the city of Lille, for its study and conservation. The examination of the artwork allowed to identify its constituent materials along with the pictorial movement and process of Georges Mathieu which enabled to understand the mechanisms that triggered the current alterations. The principal conservation issue raised by the work was the stabilization of the ongoing degradation process which were causing loss of cohesion and adhesion of the paint.

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Foreword

It is a great pleasure to present the Proceedings of the Issues in Contemporary Oil Paint (ICOP) Symposium that was held in 28–29 March, 2013, in Amersfoort at the headquarters of the Cultural Heritage Agency of the Netherlands, RCE.

Our Agency is at the heart of cultural heritage in the Netherlands. Our research group is concerned with the evaluation and preservation of our heritage in the broadest sense and the research directions we need to follow in order to guarantee a sustainable heritage. Along with national and international research partners at museums, universities and archives, we conduct research, characterise materials and analyse change processes. The Agency ensures that third parties can apply the knowledge that we can provide.

The ICOP symposium was the first symposium focused on modern paints since the Modern Paints Uncovered (MPU) conference held at Tate in 2005. Whereas MPU mainly presented research on modern synthetic paints especially on acrylics, ICOP chose to focus on modern oil paints entirely. Many modern artists continue to work with oil paints, and modern oil paints increasingly become a challenge for conservators and collection keepers. Therefore it was felt by the organisers that it was time to organise a meeting which could discuss these challenges by presenting information on historical and artistic production, scientific research on degradation phenomena, and developing alternative conservation approaches.

ICOP marked the end of a 4-year Research Agenda, for our Agency.[1] In one of the programmes in the Research Agenda, *Object in Context,* the RCE research group generated knowledge on the production of and changes in heritage objects in their artistic, cultural and social contexts. Under the leadership of Klaas Jan van den Berg, the '20th century oil paint project' contributed to the outcome of the Agenda. The project brought many institutions together and was a breeding ground for

[1] Outcomes of this Research Agenda are accessible on-line: http://www.kennisvoorcollecties.nl/en/researchagenda/.