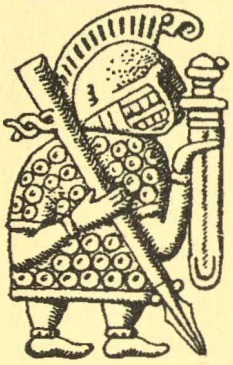

FORN VÄNNEN

JOURNAL OF SWEDISH ANTIQUARIAN RESEARCH

2018:2

Albertus Pictor
– a Medieval master painter and his pigments

By Anders G. Nord, Kate Tronner, Misa Asp and Elin Lundmark

Nord, A.G., Tronner, K., Asp, M. & Lundmark, E., 2018. Albertus Pictor – a Medieval master painter and his pigments. *Fornvännen* 113. Stockholm.

The German-born artist Albertus Pictor (†1509) was responsible for the decoration of the walls and vaults of about 35 Swedish churches. In terms of the brilliant technique and the overwhelming production volume, his workshop was outstanding in Medieval Sweden. This study analyses a total of 291 samples of pigments from nine churches containing murals attributed to the workshop. Some of the results have already been published, but here they are integrated with new data. Isotope measurements of 13 lead pigments have been made. A tenth church with a questionable attribution, Öja on Gotland, has also been investigated with nine samples.

One purpose of this study is to find out which pigments Albertus' workshop preferred. Another aim is to show how chemical data can complement art historians' judgments concerning the master of a mural. Furthermore, the origins of the pigments are discussed. Our results indicate that Albertus Pictor used a rather limited number of pigments, and that he preferred pigments from his native country, Germany.

Anders G. Nord, Kevingeringen 10, SE–182 50 Danderyd
andersgn@tele2.se
Kate Tronner, Flädergränd 2, SE–187 73 Täby
katetronner@gmail.com
Misa Asp, Konservator Misa Asp AB, Sjöbjörnsvägen 1, SE–117 67 Stockholm
misa.asp@konservering.nu
Elin Lundmark, Tottvägen 1B, SE–169 54 Solna
elin_lundmark@yahoo.com

Albertus Pictor ("Albrecht the Painter") was born around 1440 in Immenhausen near Kassel in central Germany. As a young man, he emigrated to Sweden to work as a church painter. In 1473 he settled in Stockholm, where he married the widow of Johan målare ("John the Painter") and took over the family workshop. Albertus then directed its work until his death in 1509. He was highly successful in his profession, often working for patrons of high standing, and was responsible for the decoration of about 35 churches, mainly in the Lake Mälaren area. Written sources also indicate that he was a prominent embroiderer (Geijer 1949).

In some of the churches there are more or less readable signatures by Albertus Pictor, while in others the iconography, the technique and the outstanding workmanship justify an attribution to the workshop. The life and work of Albertus Pictor have been described and discussed by many authors (e.g. Cornell & Wallin 1933; Nisbeth 1986; Svanberg 1992; Hall et al. 2003; Melin 2006, 2009; Sandquist Öberg 2009). In some churches, all the vaults and walls are still completely covered by

Fig. 1. Various motifs with the Virgin and Child in the centre. Vault mural in Härkeberga Church, Uppland. Photo Gabriel Hildebrand, National Heritage Board.

well-preserved paintings, sometimes accompanied by brief inscriptions in Latin (cf. fig. 1), while others have suffered from unprofessional restorations.

Many of the Biblical motifs have been copied from the *Biblia pauperum* or from prints, and often modified (e.g. Sandquist Öberg 2013). The characters and objects depicted illustrate the lifestyle of the late 15th century: clothes, shoes, hats, cattle, tools, musical instruments, weapons, games, and so forth (cf. Melin 2006). The margins between the religious scenes often contain ornaments and folkloristic motifs such as a hobgoblin, a porcupine or a fantasy bird with an enormous beak. In Härnevi Church there is also a fat sow playing the organ. This may be a manifestation of Medieval anti-Semitism, also expressed in other paintings of men with a hook-nose, a Jewish hat etc. (Bengtsson 2016).

The quality of the paintings is indeed impressive – the craftsmen have often created three-dimensional effects. Each person's face is usually beautifully modelled with highlights, shadows and minute details (fig. 2). Naturally, soot from candles and other kinds of dirt have darkened many paintings, and some pigments and colourants have degraded.

The churches in the study

The churches of Täby, Härkeberga, and Härnevi in Uppland are especially famous because their vaults and walls are filled with often well-preserved high-quality paintings. We have collected pigments from these churches on twelve separate occasions. Another Uppland church (Ed) is included in the study, along with two churches in Södermanland (Floda and Vadsbro), and two in Västmanland (Kumla and Sala). The paintings on the vaults of Kumla Church are of a high quality and in a good state of preservation. By contrast, the paintings on the walls were covered with lime wash in the 18th century. This was done at that time in many Medieval churches in Sweden and Denmark. Many of these paintings were later uncovered, usually causing loss of material. For this reason, the paintings were sometimes retouched. This was not always done in a professional way, and the analyses often indicate presence of modern pigments such as chromium oxide and barium sulphate. Finally, the churches in Nederluleå

Fig. 2. Moses producing water from a rock in the desert with his staff. Mural in Täby Church, Uppland. Photo Bengt A. Lundberg, National Heritage Board.

(Norrbotten) and Öja (Gotland) have been investigated. Nederluleå Church is near the Arctic Circle in the Gammelstaden World Heritage area. The paintings executed here by Albertus Pictor's workshop have been lime-washed and subsequently uncovered. Fortunately, we managed to find parts of the original paintings. Öja Church is in the southern part of the island of Gotland in the Baltic Sea. Its murals are of varying quality, some of them good but often fragmentary. It has been debated whether the paintings in Öja's chancel were decorated by Albertus Pictor and/or his workshop. This question of attribution is discussed at the end of this paper.

The samples

When collecting samples from the churches of Täby and Härkeberga, we tried to obtain pigment samples of all possible colours and nuances. These paintings have never been covered with lime. In 1993 Lars Göthberg conserved the Täby paintings, and from the scaffolds it was possible to reach almost all murals (Nord et al. 1996). In Härkeberga it was not possible to obtain samples from the vaults. The careful sampling was undertaken under the supervision of Åke Nisbeth or Lennart Karlsson.

Regarding the other churches, the sampling was partly focused on paintings in need of conservation. In all of these, the dominating colours were red, green, blue and yellow. In Härnevi, most pigment samples were taken from the scene showing The Annunciation, and in Kumla from The Death of Mary. In Nederluleå, samples were collected from the pictures of St. Matthew and St. Augustine, The Coronation of Mary, and some foliage and decorations. In Ed all samples were taken from the scene in which Jesus expels the merchants from the temple. At Floda the selected motifs were The Birth of Christ and Moses with the Burning Bush, and at Vadsbro the painting of St. Bridget of Sweden. Only a few samples were collected at Sala Old Church, and those from Öja are listed in a subsequent section. A summary of all samples of pigments from all churches, in total 300, is given in tab. 1.

Analytical methods and results

We did most of our sampling by scraping off small amounts of paint from the surface. This told us

Church	Date	No of samples analysed	Refs
Up, Ed	1487	20	d
Up, Härkeberga	1480s	78	a, b
Up, Härnevi	1480s	24	a, c
Up, Täby	1480s	60	a, b
Sö, Floda	1480s	21	e
Sö, Vadsbro	1480s	18	f
Vs, Kumla	1482	45	c
Vs, Sala	1460s	10	c
Nb, Nederluleå	1492–	15	g
Go, Öja	c. 1500	9	c
Total		**300**	

Tab. 1. Summary of investigated material from the ten churches. References: a) Nord et al. 1996, b) Nord & Tronner 2010, c) Present work, d) Tronner & Nord 2002, e) Tronner & Nord 2003a, f) Tronner & Nord 2003b, g) Nord et al. 2017a.

which pigments are present on each spot but not whether they were originally mixed or applied in layers. Some samples are cross sections where the stratigraphy of the painting can be analyses. All collected samples were analysed by SEM/EDX (JEOL JSM-840A, LEO 1445VP, Hitachi S-4300 or JEOL JSM-7000F), equipped with a LINK/Oxford unit for X-ray microanalysis. With the backscatter detector and a magnification around 100X–500X, about 10–20 small pigment grains from each sample were qualitatively and quantitatively examined by point analysis. In doubtful cases, and if the sample was large enough, X-ray diffraction with a Debye-Scherrer camera was undertaken, and occasionally a polarisation microscope was used. Many samples contain two or more various pigments. This is quite common for red colours, and to a less degree green colours. This mix of pigments was observed in all of the churches, and the number of analysed pigments is around 400 for the 300 samples.

The analytical results for the murals in the nine churches attributed to Albertus Pictor are summarized in tab. 2. The numerous results from Täby and Härkeberga are presented in three columns indicating the frequency of the used pigments: "Very common" indicates that the pigment occurs in practically all separate paintings, while "Rare" indicates a rarely occurring pigment. Between these two columns is a category denoted "Common or Less common". For the other churches, with fewer collected samples, only two columns are used. This classification may seem coarse, but nevertheless gives some indication of which pigments were routinely used and which occurred more seldom.

Quite often traces of modern "improvements" were encountered, such as chromium oxide (Cr_2O_3), barium sulfate ($BaSO4$) and titanium dioxide (TiO_2). These were particularly common in the paintings at Ed, Floda and Vadsbro, whose murals obviously suffer from hard-handed restorations. In Ed we even found cobalt blue ($CoAl_2O_4$). The green pigments malachite and atacamite may easily be distinguished by SEM/EDX analyses. If only copper, carbon and oxygen are present, the green pigment is likely to be malachite, since verdigris (a copper acetate) is unstable on a plaster of lime. Absence of carbon, presence of chlorine and a Cu:Cl atomic ratio of 2:1 instead indicates atacamite, $Cu_2Cl(OH)_3$. This was sometimes verified by X-ray diffraction. It should be stressed that four modifications of atacamite are known today (Scott 2000; Yong 2012). However, the word "atacamite" is used throughout this paper for whatever modification it might be. Red organic dyes have been identified by IR spectroscopy (FTIR) and microchemical reactions, but they were generally degraded and are usually in the tables characterized as "unknown red organic dye".

All paintings were made on a ground of lime

Church	No of samples	Frequency of the various pigments' occurrence Very common	Common or less common	Rare
Täby	60	Lime, carbon black, iron(III)oxide, minium, plattnerite	Malachite, atacamite, azurite, ochre, cinnabar, lead tin yellow, umber	Massicot, green earth, brazilin, copper vanadate, tenorite
Härkeberga	78	Lime, carbon black, iron(III)oxide, minium, plattnerite	Malachite, atacamite, azurite, ochre, cinnabar, lead tin yellow, massicot, umber	Lead white, green earth, caput mortuum, copper vanadate
Härnevi	24	Lime, carbon black, malachite, atacamite, azurite, iron(III)oxide, minium, plattnerite, lead tin yellow, unidentified red organic dye		Umber
Ed	20	Lime, carbon black, iron(III)oxide, malachite, azurite, atacamite		Ultramarine
Floda	21	Lime, carbon black, iron(III)oxide, malachite, azurite, ochre, minium, plattnerite, cinnabar, lead tin yellow		
Vadsbro	18	Lime, carbon black, iron(III)oxide, malachite, azurite, ochre		
Kumla	45	Lime, carbon black, iron(III)oxide, malachite, azurite, massicot, minium, plattnerite, cinnabar, red dye (brazilin?)		Green earth, orpiment, lead tin yellow
Sala	10	Lime, carbon black, iron(III)oxide, malachite, ochre		
Nederluleå	15	Lime, iron(III)oxide, malachite, azurite, ochre, massicot, plattnerite, green earth, lead tin yellow		

Tab. 2. Pigments occurring in nine churches attributed to Albertus Pictor. Note that plattnerite (PbO_2) and tenorite (CuO) are not original pigments but black transformation products of lead and some copper pigment respectively. Brazilin is a red organic colourant.

plaster. Our samples practically always contained a considerable amount of calcium carbonate, which seems to support the use of lime as the principal binding medium. However, the calcium carbonate might also originate from the grounding. Besides, we have occasionally also found low concentrations of (usually) degraded organic binding media, and possibly organic binders have played a greater role than has been assumed. Among these we have identified proteins, drying oils (glycerol esters) and erucic acid ($C_{22}H_{42}O_2$), the latter obtained from rapeseed oil. As a matter of fact, organic binding media were often found in murals on Gotland, painted in a Russian-Byzantine style (Nord et al. 2017c). Investigations with UV light suggest that there may have been different organic binders for different pigments, and further investigations are required to fully understand the painting technique. Pia Bengtsson Melin (2006) has also indicated that the technique used by Albertus Pictor and his workshop is clearly reminiscent of techniques used for easel paintings, as a kind of "panel painting on a ground of lime". We intend to look further into these interesting questions.

There are occasional traces of contours sketched with carbon black. Small and frequently occurring details were often painted using templates made of lead. The surface under the paintings sometimes contains gypsum and also grains

Church	Sample	Pigment	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
Härke-berga	H-23A*	Plattnerite	18.353	15.617	38.285	0.8520	2.0859
	H-24A*	Minium	18.328	15.615	38.251	0.8532	2.0870
	H-40*	Plattnerite	18.34	15.59	38.21	0.8501	2.0834
	H-47A*	Plattnerite	18.358	15.616	38.278	0.8519	2.0853
Täby	T-17*	Plattnerite	18.48	15.64	38.49	0.8463	2.0828
	T-28	Plattnerite	18.513	15.670	38.561	0.8465	2.0829
Härnevi	HV-6	Minium	18.621	15.701	38.700	0.8432	2.0783
	HV-19	Minium	18.594	15.682	38.667	0.8434	2.0795
Kumla	K-22	Massicot	18.416	15.621	38.378	0.8482	2.0838
	K-49	Minium	18.677	15.729	38.721	0.8422	2.0732
	K-50	Plattnerite	18.652	15.710	38.683	0.8423	2.0739
Neder-luleå	N-1**	Minium with some cinnabar	18.487	15.614	38.466	0.8446	2.0806
	N-2**	Plattnerite	18.422	15.622	38.437	0.8480	2.0864

Tab. 3. Lead isotope data for 13 lead pigments from Albertus Pictor's paintings. The results are given by five commonly used lead isotope ratios. The analytical errors are ±0.10% or better for ratios involving ^{204}Pb, and ca. 0.05% for the remining ratios. *Nord et al. 2015. **Nord et al. 2017a.

of sand. Thirteen lead pigments have been analysed with a MC-ICP-MS mass spectrometer to determine the isotopic composition of the lead.

Lead isotope analyses

During the Middle Ages, hundreds of lead mines were worked in Europe and elsewhere. The most common lead mineral is galena (PbS), from which the pigments massicot and minium can be prepared. Lead has four stable isotopes with mass numbers 204, 206, 207 and 208. Except for ^{204}Pb, they originate from radiogenic decay of uranium or thorium. This decay is extremely slow, so the age of the mineral deposit is an important factor for its lead isotope composition. Accordingly, the isotopic variations in the lithosphere are considerable, which is favourable when attempting to use lead isotopes to reveal the provenance of the lead in e.g. an artefact or pigment. The relative isotopic abundances of 13 lead pigments sampled from Albertus Pictor's paintings are given in tab. 3. The analyses were performed with a MC-ICP-MS mass spectrometer of the type Micromass Isoprobe or a ThermoScience spectrometer model ELEMENT-XR.

The isotopic composition of a lead-bearing substance is identical with that of the lead ore from which it was once manufactured. This forms the basis for using the lead isotope composition as a fingerprint of the origin of the lead. A disagreement between data for a sample and an ore deposit, respectively, shows that the analysed lead cannot originate from the deposit in question. A match indicates that the lead *may* originate from that specific deposit. Notes on the interpretation of isotope ratios of lead pigments have been presented in a recent paper (Nord et al. 2015). It is obvious that all lead pigments listed in tab. 3 originate from Palaeozoic to Mesozoic (545-65 Ma) terrains, most likely from the Harz or Erzgebirge districts in Germany, although not from a single mine (Lévêque & Haak 1993; Niederschlag et al. 2003; Monn et al. 2008). Perhaps coincidentally, Albertus Pictor was from Immenhausen not far from the Harz.

The pigments of Albertus Pictor

So far, we have analysed more than a thousand samples of pigments from Medieval murals in about 50 Swedish churches. Tab. 4 summarises all Medieval pigments (and other colourants) identified during these studies. Some chemical and/or mineralogical data are included. The column "Frequency" in the table indicates pigments or colourants used by Albertus Pictor's workshop in the examined churches. Six of the pigments in the list were probably never used (N), and eleven in the table are classified as "rare" (R) since they have very rarely been identified. Tab. 4 shows that a limited number of pigments have been classified as "Very Common" or "Common".

For black and white, Albertus Pictor almost always used carbon black and lime. Lead white is rare. Gypsum (calcium sulfate dihydrate) is often found in the samples. It is uncertain, though, whether it was used as a white pigment or added for other reasons, e.g. to improve the lime ground. (Since industrialisation, gypsum often forms on limestone and marble from sulphurous gases in polluted city centres. However, this kind of transformation has certainly not taken place inside rural Swedish parish churches.)

For yellow, the preferred pigments were ochre and massicot. For haloes, and for highlights on yellow parts in general, the more expensive pigment lead tin yellow was frequently used. Lead tin yellow was introduced at the end of the Middle Ages and was probably made in glass workshops. The composition may change from Pb_2SnO_4 (a lead stannate) to ~$Pb(Sn,Si)O_3$ or ~$PbSn_2SiO_7$. All those we encountered contained silicon, i.e. they correspond to the two latter formulae. We have also noted that lead tin yellow darkens on a ground of lime. In a few samples we identified lead antimonate ("Naples yellow") or orpiment (an arsenic sulphide), but never gold.

For red, iron(III)oxide (Fe_2O_3), minium (Pb_3O_4, also called "red lead") and the more expensive pigment cinnabar (HgS) were commonly used, often in various layers to create a three-dimensional effect. (Mercury sulphide was also prepared from liquid mercury and sulphur during the Middle Ages with the name "vermilion", but for convenience we prefer to use the mineral name, *cinnabar*). Unfortunately, the red minium used to paint most details on faces has with time become completely oxidized to black plattnerite (β-PbO_2). This alteration is also visible on many clothes painted with this pigment (fig. 3). Red lake dyes seem to have been used quite extensively in some of the paintings, but the colour has to a large degree degraded. Further research is in

Fig. 3. The Visitation in Härnevi Church, Uppland. Photo Elin Lundmark.

Fig. 4. A Prophet with an inscription in Latin. Painting in Täby Church. The large collar was painted with red brazilin, which has degraded almost completely. Photo Kate Tronner.

Colour	Name	Chemical composition; mineralogical information	Frequency
White	Lime	Calcium carbonate, $CaCO_3$	VC
	Lead white	Synthetic product $2PbCO_3.Pb(OH)_2$. Also exists as the mineral hydrocerussite	R
	Gypsum	Mineral, $CaSO_4 \cdot 2H_2O$	C
Black	Carbon black (charcoal)	C	VC
	Black iron oxide	Natural mineral Fe_3O_4	N
	Plattnerite*	Lead dioxide, β-PbO_2 (oxidized form of a lead pigment, i.e. not a natural pigment)	C
	Tenorite*	CuO; transformed from azurite	R
	Metacinnabarite*	Black modification of HgS	R
Yellow	Ochre	Earth colour containing iron oxide(s)	C
	Massicot	The mineral PbO (also exists as a synthetic product)	C
	Lead tin yellow	Synthetic product ~$PbSn_2SiO_7$	R
	Orpiment	Mineral As_2S_3	R
	Naples' yellow	Lead antimonate, $Pb_3(SbO_4)_2$, synthetic product	R
	Volborthite**	$Cu_3V_2O_7(OH)_2 \cdot 2H_2O$, secondary mineral in malachite	R
	Gold	Metallic; Au	N
Red	Iron oxide	Fe_2O_3 (natural or synthesized)	VC
	Minium	Synthetic product Pb_3O_4	C
	Cinnabar	Mineral HgS (also a synthetic product, "vermilion")	C
	Realgar	Mineral As_2S_2	N
	Brazilin	A natural red dye from Brazil wood ("Brazilwood red")	R
	Organic red colourant	Un-identified red organic dyes	R
Violet	Caput mortuum	Violet modification of Fe_2O_3	R
Brown	Umber	Earth pigment, clay rich in iron and manganese	C
Green	Malachite	Mineral $CuCO_3.Cu(OH)_2$	C
	Atacamite	Rare mineral in Europe. A synthetic form of $Cu_2Cl(OH)_3$ may have been used	C
	Green earth	Iron-rich pale green natural silicate	C
	Green vivianite	Rare mineral with the approximate composition $Fe_3(PO_4)_2.8H_2O$. (May also be blue)	N
Blue	Azurite	Mineral $2CuCO_3.Cu(OH)_2$	C
	Ultramarine	Pigment from the mineral *lapis lazuli*, with the approximate composition $(Na,Ca)_6(AlSiO_4)_6(S,SO_4,Cl)$	R
	Blue vivianite	Rare mineral with the approximate composition $Fe_3(PO_4)_2.8H_2O$. (May also be green)	N
	Smalt	Cobalt glass	N

Tab. 4. Pigments and other colourants identified by the authors from Medieval murals in 50 Swedish churches (more than 1000 samples). The column "Frequency" refers to the classification in tab. 2 for the nine churches' paintings attributed to Albertus Pictor, with the following abbreviations: VC = Very common, C = Common or Less common, R = Rare, N = Never identified in any of Albertus Pictor's paintings.
* Transformed from another pigment. **A secondary mineral in malachite.
Modern pigments used for later "improvements" are not included in the table.

progress with the hope to settle this question. Brazilin has been identified in one painting (fig. 4). It is not a pigment but the main organic constituent ($C_{16}H_{14}O_5$) in the complex brazilwood lake dyes. The darker pigment caput mortuum, a violet modification of Fe_2O_3 obtained by heating the iron oxide to about 1000°C, has not seen much use. Umber, an earth pigment, was used for brown. Finally, another question needs to be answered. It is uncertain whether the characters' faces were originally as bright as they appear today, with a light grey shade. They *may* originally have been coloured with a red or pink colourant.

For many years, researchers routinely classified most green pigments as malachite or possibly verdigris (a copper acetate). Verdigris, though, was preferably used in panel or canvas paintings because it darkens on an alkaline ground such as lime (Thompson 1956; Hansen & Jensen 1991; Scott 2000; Coccato et al. 2017). Our studies have shown that the copper chloride *atacamite* is common in Medieval murals in Sweden, including those by Albertus Pictor's workshop. As a matter of fact, painters sometimes used a mixture of malachite and atacamite. Neither atacamite nor malachite are found in Swedish bedrock, but they may have been imported. Both minerals occur on the Continent, e.g. in the mountainous regions of Germany, in Cornwall, and in Russia, although atacamite is less common than malachite. The leading trade organisation in the Baltic Sea area around 1150–1600 was the Hanseatic League, with centres in south Sweden and all around the Baltic Sea. Both malachite and atacamite may have been imported to Sweden. However, atacamite might also be a synthetic product. It can easily be made from metallic copper, table salt and oxygen from the air. Scott (2000) has verified the method, and we have also tested it. In a few months crystals of atacamite form. In fact, atacamite is often found on outdoor bronze statues near the sea (Nord et al. 2001).

Many authors have suggested that atacamite was formed through a chemical transformation of another copper pigment such as azurite or Egyptian blue. For instance, many cases are known where the artificially produced pigment Egyptian blue has reacted with some chlorine-containing compound to form atacamite, thus changing colour from blue to green (Scott 2016). Also, the much more common blue azurite is reported to have transformed into atacamite (e.g. Naumova et al. 1990; Lluveras et al. 2010). Even malachite may be transformed to atacamite (Scott 2016). All of these transformations require chlorine. Already in 1972 Kerber et al. reported a change from azurite to atacamite, which they could explain by reference to the presence of a layer of sodium chloride under the paint. In Egypt, wind-borne salt from the Mediterranean Sea is likely to react with Egyptian blue to form atacamite. This process was once called "copper chloride cancer".

As regards our more than 1000 analysed samples of pigments, chlorine was never found except when atacamite was present. On Gotland, the inevitable presence of wind-borne salt from the Baltic Sea may transform azurite into atacamite, thus changing the colour from blue to green. We have analysed green pigment traces on outdoor church portals on Gotland (Nord et al. 2014), and on one church (Martebo) blue azurite on a woman's dress has probably transformed into green atacamite. But salt from the Baltic Sea is not likely to penetrate into a church with all doors and windows closed and located some 100 km from the coast. Besides, most details painted with atacamite were leaves or foliage, which most certainly were never blue. No striking or conspicuous colour changes were observed in the murals' blue tints. Furthermore, in many of Albertus Pic-

tor's productions, malachite and atacamite were found in the same painting. This is an indication that a mixture of both minerals was probably bought and used as a green pigment. Possibly the chemical difference between the two pigments was unknown at the time.

Green earth is not as common as the other green pigments, and nor have we found green or blue vivianite in any of Albertus Pictor's paintings. Vivianite is nevertheless an interesting pigment. It is a rare mineral in Europe, mainly found in Cornwall, Germany and Russia. The basic composition of this iron phosphate mineral is $Fe_3(PO_4)_2 \cdot 8H_2O$, but small amounts of other metals may substitute for the iron and cause a colour change (Strunz & Nickel 2001; Scott & Eggert 2007).

For blue, Albertus Pictor's workshop almost always used azurite. Among our 42 blue pigment samples, only one was found to contain ultramarine. All the others were azurite. In many of the paintings, modern "improvements" have been made, not always in a professional and sensitive way. In particular, chromium oxide (Cr_2O_3) and barium sulfate ($BaSO_4$) have been identified during the analyses, and even titanium white (TiO_2) and cobalt blue ($CoAl_2O_4$), first synthesized around 1800 by the French chemist Louis Thenard.

A few words about the origins of the pigments. The most common ones such as carbon black (charcoal), lime, gypsum, green earth and iron oxides may have been obtained locally. The commonly used red iron oxide Fe_2O_3 for instance may be collected from hematite mines or as bog iron, Sw. *myrmalm*, an iron hydroxide mineral that accretes in lakes. Atacamite may as discussed above have been prepared synthetically, in Sweden too. All other pigments must have been imported. The lead pigments' isotope composition indicates a German origin. Furthermore, the presence of copper vanadate as a secondary mineral in malachite points in the same direction (Nord et al. 2012). Except for cinnabar, ultramarine (one sample) and brazilin, all colourants were probably imported from Albertus Pictor's native country, Germany, which was the leading mining nation in Europe during the Middle Ages. Cinnabar may have been imported from Spain or the Balkans. The exclusive and expensive blue ultramarine (*lapis lazuli*) was imported from Afghanistan. We have identified this pigment only rarely in some Romanesque murals in Swedish churches and on a 12th century baptismal font in Stånga Church (e.g. Nord et al. 2016; 2017b). Quite likely the much cheaper and more accessible, although less stable, azurite came to replace the expensive ultramarine. Many centuries later, around 1830, ultramarine could finally be prepared synthetically.

It is now well known that lead pigments painted on a ground of plaster (lime) often darken with time. In particular, massicot and minium may very slowly transform into (usually) black plattnerite, β-PbO_2 (Giovannoni et al. 1990; Nord et al. 1996). This requires oxygen from the air as an oxidising agent. However, we have observed that minium and massicot are preserved on wood and stone. It thus seems that lime, and possibly some other factor(s), acts as a kind of catalyst for the oxidation process. The "plattnerite problem" has been discussed by several authors, suggesting a number of substances which may accelerate the oxidation, such as moisture, inorganic salts, air pollutants and microorganisms (e.g. Petushkova & Lyalikova 1986; Giovannoni et al. 1990; Aze et al. 2007; Kotulanová et al. 2009). Nord and Tronner have sometimes found that the transformation to plattnerite has *not* occurred when an organic substance was present in the lime ground (Garde and Mästerby Churches, Gotland). Perhaps certain organic substances instead inhibit the oxidation. However, more studies are needed to confirm this hypothesis. It should also be mentioned that azurite may partly degrade to black tenorite (CuO), which seems to darken the blue colour (Gutscher et al. 1989). We have seen this in some of Albertus Pictor's paintings.

Nederluleå and Öja

Finally, the question of attribution for the murals in Nederluleå and Öja. The analytical results for these churches are given in tab. 5. An attribution should be based on the following observations: a) the motifs, accomplishment and quality of the paintings; b) dating; c) a legible signature; and d) the materials used. As regards Nederluleå Church, all these qualifications are fulfilled. Experienced

Nederluleå Church (Norrbotten)			
Motif	**Detail, colour**	**Number**	**Identified pigments**
St. Augustine	Red colour in his headgear	N-1	Minium with traces of cinnabar
	Yellow colour in the halo	N-2	Ochre with some gypsum.
	Blue colour	N-3	Azurite; grains of sand
St. Matthew	Yellow colour in an ornament	N-5	Ochre; traces of massicot and orpiment
	Black colour on a painted lath	N-8	Plattnerite
	Dress with a pale grey colour	N-10	Mainly lime with some gypsum and traces of iron
	Red colour made to pattern	N-11	Iron(III)oxide, gypsum
	Brown and green section	N-12	Malachite, iron(III)oxide
An angel	The angel's green dress	N-6a	Malachite with some gypsum
	The green dress, another sample	N-6b	Malachite with gypsum
Flower ornament	Green colour	N-7	Malachite and green earth; traces of lead white, grains of sand, and iron. Also barium sulfate and chromium oxide (Cr_2O_3), i.e. recent "improvements"
Coronation of the Virgin Mary	Yellow colour	N-13	Massicot, lead tin yellow, traces of orpiment
Unknown motif	Blue colour	N-15	Azurite with some green earth
	Pale blue colour	N-16	Azurite with green earth, lots of lime, grains of sand, traces of lead and arsenic.
The return from Egypt	Yellow girdle	N-17	Massicot, gypsum, grains of sand
Öja Church (Gotland)			
Motif	**Detail, colour**	**Number**	**Identified pigments**
The man in the tree of life.	Red colour made to pattern	Ö-1	Iron(III)oxide
	Reddish-brown cap on the man's head	Ö-2	Iron(III)oxide, carbon black,
	The man's greet foot (a sock?)	Ö-3	Atacamite, gypsum
	Olive-green lawn	Ö-4	Vivianite, carbon black; modern "improvements" with barium sulfate, titanium dioxide and viridian ($Cr_2O_3.2H_2O$)
Gideon and an inscription in Latin (fig. 5).	Yellow colour traces from the angel's halo	Ö-5	Massicot
	Dark grey text	Ö-6	Carbon black, traces of iron
	Black paint below the man	Ö-7	Carbon black
	Green colour	Ö-8	Atacamite
	Red colour in the border surrounding the painting	Ö-9	Iron(III)oxide

Tab. 5. Analytical results of the pigment samples from the churches at Nederluleå and Öja. Lime was always found and is not included in the table.

Fig. 5. Damaged painting in the chancel of Öja Church, Gotland. To the left Eve and the serpent, to the right Gideon and the fleece. Photo Marianne Gustafsson Belzacq.

art historians declare that the beautiful paintings should be attributed to Albertus Pictor's workshop (Nisbeth 1986; Melin 2006), and Jan Öberg (2006) has found a damaged signature in the church, deciphered as "Albe.....t..". Besides, our chemical results for Nederluleå correspond with the pigments listed in tab. 4. It may be doubted, though, if Albertus Pictor was active in person – he was rather old at the time and the church is very far from Stockholm.

The possible contribution of Albertus Pictor's workshop to the paintings in the chancel of Öja Church on Gotland is more doubtful. Two damaged paintings are shown in fig. 5, illustrating Eve and the serpent and Gideon and the fleece, accompanied by a brief inscription in Latin. The style and iconography differ from other Late Medieval paintings by various masters in the island's churches, which indicates that the painter (or workshop) came from the mainland. However, the quality is not up to the standard of Albertus Pictor's workshop. This is particularly obvious when you compare the depiction of "The man in the Tree of Life" in Öja Church with Albertus Pictor's illustration of the same motif in Husby-Sjutolft Church.

Art historians have suggested that the decorations in Öja Church were made by a painter from Uppland or Denmark who may have been inspired by Albertus Pictor (Nisbeth 1986; Melin 2006; Gotland belonged to Denmark during the period 1361–1645). The dating, though, is reasonable. Among the pigments analysed, vivianite was found, never identified in paintings attributed to Albertus Pictor or his workshop. Also, massicot was used for the halo. Moreover, the red "favourite pigment" of the workshop, minium, was not found in Öja. (As we found no lead pigment, no isotope analysis was undertaken). Accordingly, the conclusion must be that Albertus Pictor or his workshop were *not* responsible for the paintings in Öja's chancel.

Conclusions

About 400 various pigments from ten churches have been analysed, mainly by SEM/EDX but in some cases also by X-ray diffraction, FTIR, GC-MS, MC-ICP-MS or microchemical reactions. As regards the painting technique, we question whether the paintings were usually painted with slaked lime as the only binder on lime plaster grounding. The various pigments and dyes identified are discussed. The results from the nine churches with paintings signed by, or attributed

to, Albertus Pictor's workshop indicate the use of a somewhat limited palette, with many of the pigments probably imported from the artist's native country, Germany. For red, iron (III)oxide, minium and cinnabar were frequently used, and quite often applied in various layers or mixed to create a three-dimensional effect. There is also evidence for the use of organic dyes (e.g. red lakes). Other common pigments are massicot, malachite, atacamite, and azurite. Lead tin yellow was preferred to paint haloes, and occasionally for other yellow details. Blue or green vivianite has never never identified, and only one sample with ultramarine has been identified (Ed Church). The collected data have been used to help support attributions in two churches (Nederluleå and Öja). Our conclusion is that for Nederluleå, the present study agrees with art historians' judgement that Albertus Pictor's workshop painted these murals. On the other hand, the workshop is not likely to have decorated the chancel of Öja Church.

Acknowledgements

We wish to express our sincere gratitude to the Berit Wallenberg Foundation for a generous research grant (BWS 2016.0002). And to the University of Stockholm and the Swedish Museum of Natural History for use of their scanning electron microscopes. Many thanks to Kjell Billström (Museum of Natural History) for the lead isotope analysis of sample K-22, and to Mads Christian Christensen (National Museum of Denmark) for valuable discussions. Finally, many thanks to Marianne Gustafsson Belzacq (Gotland) and Hélène Svahn Garreau (Stockholm) for use of their collected samples. Posthumously, we would also like to acknowledge the invaluable help that we received for many years from the late art historians Åke Nisbeth and Lennart Karlsson, and from conservator Lars Göthberg.

References

Aze, S., Valler, J.M., Pomey, M., Baronnet, A. & Grauby, O., 2007. Red lead darkening in wall paintings: natural ageing of experimental wall paintings versus artificial ageing tests. *European Journal of Mineralogy* 19. Stuttgart.

Bengtsson, H., 2016. Samtida mode eller antisemitism? Demonisering och rasistiska tendenser i medeltidens bildkonst. *Iconographisk post: nordisk tidskrift för bildtolkning* 2016:3/4. Åbo.

Coccato, A., Moens, L. & Vandenabeele, P., 2017. On the stability of Medieval inorganic pigments: a literature review of the effects of climate, material selection, biological activity, analysis and conservation treatments. *Heritage Science* paper 5:12. Amsterdam.

Cornell, H. & Wallin, S., 1933. *Uppsvenska målarskolor på 1400-talet*. Stockholm.

Geijer, A., 1949. *Albertus Pictor – målare och pärlstickare.* Statens Historiska Museum och Riksantikvarieämbetet, Stockholm.

Giovannoni, M., Matteini, A. & Moles, A., 1990. Studies and developments concerning the problem of altered lead pigments in wall paintings. *Studies in Conservation* 35. London.

Gutscher, D., Mühlenthaler, B., Portmann, A. & Reller, A., 1989. Conversion of azurite into tenorite. *Studies in Conservation* 34:3. London.

Hall, T., Melin, P., Sandquist Öberg, C., Svanberg, J. & Öberg, J., 2003. Albertus Ymmenhusen alias Albertus Pictor. *Fornvännen* 98.

Hansen, F. & Jensen, O.I., 1991. *Farvekemi – uorganiske pigmenter.* Copenhagen.

Kerber, G., Koller, M. & Mairinger, F., 1972. Studies of blue-green alterations in Austrian Medieval wall-painting. *ICOM Committee for Conservation, 3rd Triennial Meeting*. Madrid.

Kotulanová, E., Bezdička, P., Hradil, D., Hradilová, J., Svarcová, S. & Grygar, T., 2009. Degradation of lead-based pigments by salt solutions. *Journal of Cultural Heritage* 10. Amsterdam.

Lévêque, J. & Haak, U., 1993. Pb isotopes of hydrothermal ores in the Harz. *Monograph series on mineral deposits* 30. Berlin.

Lluveras, A., Boulerand, S. & Andreotti, A., 2010. Degradation of azurite in mural paintings – distribution of copper carbonate, chloride and oxalates by SR-FTIR. *Journal of Applied Physics* 99. Melville, NY.

Melin, P., 2006. *Fåfängans förgänglighet. Allegorin som livs- och lärospegel hos Albertus Pictor*. Stockholm University.

– 2009. *Albertus Pictor, målare av sin tid, del I. Bilder i urval samt studier och analyser*. KVHAA. Stockholm.

Monn, F., Hamer, K., Lévêque, J. & Sauer, M., 2008. Pb isotopes as a reliable marker of early mining and smelting in the Northern Harz province (Lower Saxony, Germany). *Journal of Geochemical Exploration* 68. Amsterdam.

Naumova, M.M., Pisareva, S.A. & Nechiporenko, G.O., 1990. Green copper pigments of old Russian frescoes. *Studies in Conservation* 35. London.

Niederschlag, E., Pernicka, E., Seifer, T. & Bartelheim, M., 2003. The determination of lead isotope ratios by multiple collector ICP-MS: a case study of Early

Bronze Age artefacts and their possible relation with ore deposits of the Erzgebirge. *Archaeometry* 45. Oxford.

Nisbeth, Å., 1986. Bildernas predikan. Medeltida kalkmålningar i Sverige. Stockholm.

Nord, A.G., Tronner, K., Nisbeth, Å. & Göthberg, L., 1996. Färgundersökningar av senmedeltida kalkmålningar. *Konserveringstekniska Studier* RIK-12. Riksantikvarieämbetet, Stockholm.

Nord, A.G., Tronner, K. & Boyce, A., 2001. Atmospheric bronze and copper corrosion as environmental indicator – a study based on chemical and sulphur isotope data. *Water, Air and Soil Pollution* 127. Dordrecht.

Nord, A.G. & Tronner, K., 2010. *Medeltidsmästarnas färgval*. Riksantikvarieämbetet, Stockholm. samla.raa.se

Nord, A.G., Tronner, K. & Björling Olausson, K., 2012. Copper vanadate minerals found in Mediaeval mural paintings. *Studies in Conservation* 5. London.

Nord, A.G. & Tronner, K., 2014. Färganalys av fem gotlandskyrkors portaler och muralmålningar. *Fornvännen* 109.

Nord A.G., Billström, K., Tronner, K., Björling Olausson, K., 2015. Lead isotope data for provenancing mediaeval pigments in Swedish mural paintings. *Journal of Cultural Heritage* 16. Paris.

Nord, A.G, Tronner, K., Billström, K. & Gustafsson Belzacq, M., 2016. Pigment traces on Medieval stonework in Gotland's churches – examination of seven 12th century baptismal fonts and a limestone pew. *Fornvännen* 111.

Nord, A.G., Tronner, K., Billström, K., Asp, M., Lundmark, E. & Björling Olausson, K., 2017a. Pigmentanalys av medeltida muralmålningar i sju norrlandskyrkor. *Fornvännen* 112.

Nord, A.G., Lundmark, E., Asp, M., Tronner, K. & Billström, K., 2017b. Pigmentanalys av 1100-talsmålningarna i Torpa kyrka, Kungsör. *Fornvännen* 112.

Nord, A.G., Tronner, K., Billström, K. & Strandberg Zerpe, B., 2017c. Analysis of medieval Swedish paintings influenced by Russian-Byzantine art. *Journal of Cultural Heritage* 23. Paris.

Petushkova, J.P. & Lyalikova, N.N., 1986. Microbiological degradation of lead-containing pigments. *Studies in Conservation* 31. London.

Sandquist Öberg, C., 2009. *Albertus Pictor, målare av sin tid, del II. Samtliga bevarade motiv och språkband med kommentarer och analyser*. KVHAA. Stockholm.

– 2013. *Biblia pauperum – de fattigas bibel: en rik inspirationskälla för senmedeltiden.* KVHAA. Stockholm.

Scott, D.A., 2000. A review of copper chlorides and related salts in bronze corrosion and as painting materials. *Studies in Conservation* 45. London.

– 2002. *Copper and bronze in art – corrosion, colorants, conservation*. Getty Conservation Institute. Los Angeles.

– 2016. A review of ancient Egyptian pigments and cosmetics. *Studies in Conservation* 61. London.

Scott, D.A. & Eggert, G., 2007. The vicissitudes of vivianite as pigment and corrosion product. *Reviews in Conservation* 8. London.

Strunz, H. & Nickel, E.H., 2001. *Mineralogical Tables*. Stuttgart.

Svanberg, J., 1992. *En vägvisare till Albert målares kyrkor*. Stockholm.

Thompson, D.V., 1956. *The materials and techniques of Medieval painting*. New York.

Tronner, K. & Nord, A.G., 2002. Analysrapport Raä A-118/2002. Stockholm.

– 2003a. Analysrapport Raä A-95/2003. Stockholm.

– 2003b. Analysrapport Raä A-94/2003. Stockholm.

Yong, L., 2012. Copper trihydroxychlorides as pigments in China. *Studies in Conservation* 57. London.

Öberg, J., 2006. En nyupptäckt signering av Albertus Pictor i Nederluleå kyrka. *Fornvännen* 101.