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Printing and imprinting the *Missale Nidrosiense*: a multidisciplinary investigation of the first printed book of Norway

Chiara Palandri[1*], Tuuli Kasso[2*], Aoife Daly[3], Nina Hesselberg-Wang[1], Jiří Vnouček[4], Jan Bill[5], Heidi Debreczeny Wilkinson[6], Ljiljana Puskar[7], Hartmut Kutzke[5], Sarah Fiddyment[8] and Matthew J. Collins[2,8]

Abstract

In our study, we employed an interdisciplinary approach to study the diverse parts of the *Missale Nidrosiense*, published in 1519. Our aim was a thorough investigation of the materials used and the manufacturing methods that may give indications on dating and provenance of the components of the book and where the book was bound. Initially, visual and multispectral methods were employed to investigate the books' components, printing technology and bookbinding structure. Subsequently, other methods were applied: the composition of metallic components was determined by X-ray fluorescence spectroscopy (XRF). Pigments, printing inks and binders were characterised by using a combination of XRF and synchrotron-based infrared microscopy. Non-invasive dendrochronology based on X-ray tomography was utilised, to indicate date and provenance of the wooden boards of the book. Additionally, we used a biocodicological approach to identify the species of animal used in the parchment. This resulted in a complete biography of the book. We were able to acquire new information about the materials used and their provenance. This provides new information about craft, economy, trade and commercial exchange in the beginning of the sixteenth century in North-west Scandinavia, despite the lack of written documentation from this period.

Keywords Dendrochronology, Biocodicology, Provenance, Baltic oak trade, Bookprinting, Norway

*Correspondence:
Chiara Palandri
chiara.palandri@nb.no
Tuuli Kasso
tuuli@palaeome.org
[1] National Library of Norway, Henrik Ibsens Gate 110, 0203 Oslo, Norway
[2] The Globe Institute, University of Copenhagen, Øster Farimagsgade 5, 1353 Copenhagen, Denmark
[3] Dendro.DK V/Aoife Daly, Fuglsang Alle 111, 2700 Brønshøj, Denmark
[4] Department of Preservation, The Royal Library, 1016 Copenhagen, Denmark
[5] Museum of Cultural History, University of Oslo, Postboks 6762 St. Olavs plass, 0130 Oslo, Norway
[6] Norwegian Geotechnical Institute, Sandakerveien 140, 0484 Oslo, Norway
[7] Institute for Electronic Structure Dynamics, Helmholtz-Zentrum Berlin Für Materialien Und Energie GmbH, Albert-Einstein-Straße 15, 12489 Berlin, Germany
[8] The McDonald Institute for Archaeological Research, University of Cambridge, Downing St, Cambridge CB2 3ER, UK

Introduction

The printing of the two books, *Breviarium Nidrosiense* and *Missale Nidrosiense*, in 1519 introduced the technology and art of letterpress printing to Norwegian book production. The books are part of Norway's Documentary Heritage, and since 2012 they have been listed among the Norwegian contributions to UNESCO's Memory of the World Programme. In this article we present the research that has been carried out since 2019 on several copies of *Missale Nidrosiense.* (Fig. 1) Our aim was to analyse all the individual parts of the book independently in order to obtain a holistic description and understanding of a single, multi-material object. The target for the analysis were three copies of the *Missale* as well as a loose

Fig. 1 **a** Cover of NB D Pal 42 *Missale Nidrosiense*. Note the metal clasps. **b** Similarities in the bindings' structure and attributes indicate that the same bookbinder executed the copies we have observed (NB D Pal 44, NB D Pal 43, NB D Pal 42)

cover without textblock kept in the National Library of Norway and seven further copies present in other collections in Norway.[1] Even if the preserved volumes are few in number, we were able to identify many characteristic shared features, which suggests a very schematic and almost identical production. This is despite the fact that many of the constituent elements were produced, collected or used in very different geographical areas. These features could be observed from various types of evidence, ranging from the supply of the paper to the binding of the volume.

Biography of the book

Until 1519 priests in Norway mainly used handwritten books with texts dating as far back as to the eleventh century, and given the textual variation that occurs in manuscript culture, there could be significant deficiencies and deviations in these texts. Although a large part of the liturgy was common to all of Europe at the time, foreign texts could not entirely replace these handwritten books since they would have lacked masses for the celebrations of some of the Norwegian saints. The high cost of books was a major reason to keep the old books and continue using them despite their textual variation [1].

With the aim of standardising the liturgy for the entire ecclesiastical province of Nidaros,[2] Archbishop Erik Valkendorf (*c.* 1465–1522) initiated the printing of the two books, *Breviarium Nidrosiense* and *Missale Nidrosiense* [2]. The *Breviarium* was a small octavo "pocketbook" intended for the priests for recitation of the Canonical Hours, while the *Missale* was a folio mass book intended for the altar. The Archbishop paid for the printing of the *Breviarium* so that it could be sold at a reasonable price.[3] The price

[1] Of a total of eighteen surviving copies of *Missale Nidrosiense*, we have examined ten located in Norway: three copies and a cover without textblock belong to the National Library (NB D Pal 42, NB D Pal 43, NB D Pal 44 in the collection of early printed books and Ms.fol. 3858 in the manuscript collection), three copies in Gunnerus Library in Trondheim, one copy in the University Library in Bergen, two copies in *Deichmanske bibliotek* (Oslo's municipal library) and one copy belongs to Oppdal church. The other surviving copies are held by the British Library (C.52.h.9) in London, *Bibliothèque Nationale* in Paris, the Vatican Library, three copies belong to the Royal Library in Copenhagen and two copies are held by private owners. The copy of the Missale owned by Olav Engelbrektsson, the last Catholic bishop in Norway, became a part of Count Palatine's library in Heidelberg in the 1540 s and was later transferred to *Palatino Vaticani* (Stamp.Pal.II.419).

[2] The province of Nidaros included the whole of Norway with Härjedalen, Bohuslän, Iceland and the Faroe Islands. Jämtland was Norwegian but the province belonged to the Uppsala archdiocese.

[3] The printing of the *Breviarium Nidrosiensis* was commissioned to Jean Kerbriant and Jean Bienayse, who were among the most prominent book printers in Paris at the time, and it was carried out under the supervision of Hans Reff (*c.* 1490–1545), the Archbishop's canon.

of one *Breviarium* was three *Rhenish guilder* [3],[4] which corresponded to two and a half cows [4]. In the foreword Valkendorf enjoins all the clergy of his province to acquire a copy of the *Breviarium*, and he grants all buyers forty days of indulgence [5]. The print has been characterised as 'one of the most beautiful specimens of its kind' [6].

The printing of the *Missale* was commissioned to Poul Reff (†1533), canon and former Head of the University and the first native letterpress printer in Copenhagen [6, 7]. In 1513 Reff had taken over the printing press of Matthäus Brandis (†1512) from Lübeck; Brandis had printed the Danish *Missale Hafniense*[5] in 1510 and thus possessed the types needed [6]. The printing started in 1516 and was completed on 25 May 1519. The Norwegian Missale is considered Poul Reff's main work, and it is one of the most prominent Danish prints before King Christian III's bible from 1550 [6]. It is not known how many copies were printed, but the Archbishop's idea was that all of the approximately 1550–1600 churches should have a *Missale* [8]. Several copies have a clear provenance to specific Norwegian churches, which bears witness to widespread distribution.[6] The *Missale* was the main book used during mass; it followed the church year and the saints' year, and it contains songs, prayers and bible lessons. With its Latin liturgy, the *Missale* was in use for the primary church festivals until the 1680 s, far beyond the Reformation in 1537 [9, 10].

Trade and economy in Norway, 1500–1519

At the beginning of the sixteenth century, trade opportunities opened up in Norway through traditional resources such as fishing, forestry and mining. The water-powered sawmill and extraction of rock iron ore were new technological inventions, and new markets in Europe led to the strongest period of economic recovery in the country's history. In the wake of the Black Death in 1350 and countless pandemics in the years after, Norway's population was reduced to only 150,000 inhabitants in the year 1500, and as a result of this drastic decrease in population, the country's infrastructure was debilitated.

Late medieval Norway was a society with relatively little or no social differentiation, with few or no privileges for anyone. The church was the country's largest landowner. The bishops came to form an increasingly large part of the Norwegian Council, and their influence grew accordingly. The church was even in charge of law enforcement. The archbishop was the obvious chairman until the reformation in 1537 [11].

Materials

We investigated three copies of *Missale Nidrosiense* (NB D Pal 42, NB D Pal 43, NB D Pal 44) and a loose *Missale* cover without textblock (Ms.fol. 3858) [12][7] belonging to the National Library of Norway's collection of early printed books and collection of manuscripts. Furthermore, the binding and its decoration, the paper and the printing technique of the seven remaining preserved copies in Norway were visually analysed, and all the relevant data for comparison with the copies at the National Library were collected.

Bookbinding

The original binding (Fig. 2a) is preserved in its original state on seven of the ten analysed copies of the *Missale* (in addition to the National Library's loose cover). It can be described as a contemporary European full leather binding of Gothic type, folio format. The *Missale* was delivered unbound [13], and the binding operation most probably took place in Nidaros [14]. Similarities in the bindings' structure and attributes indicate that the same bookbinder executed the copies we have observed. The *Missale* is covered in brown leather [14], richly decorated with blind tooling on both boards and equipped with metal furniture. The wooden boards have square corners and straight cut edges with a bevelled edge towards the spine. The leather turn-ins are trimmed and mitred but not paired at the corners. Measurements differ slightly for the three copies in the National Library's collection, but they are approximately 350 mm high, 250 mm wide and 70 mm thick.

The textblock of NB D Pal 44 is the only complete copy, consisting of thirty-nine gatherings, the majority of which have four double leaves, two gatherings have three double leaves (31 and 38) and the final gathering has only two double leaves with one blank leaf torn out.

The textblock sewing (all-along sewing) is on four double raised bands in addition to two changeover stations above and below the supported area of the spine. Endbands are not present on any of the copies and could simply have been left out for financial reasons or shortage of time. The wooden boards were attached to the bookblock by sewing support slips drawn through drilled holes and tunnels, and they were secured with square wooden pegs from the internal sides of the boards.

Separate endleaves, also used as paste downs, were sewn together with endleaf guards of large handwritten

[4] The price of one *Breviarium* is noted in *Diplomatarium Norvegicum* in an inventory by Valkendorf from 1521.

[5] *Hafnia* is the Latin name for Copenhagen, from the old Danish *hafn*, harbour.

[6] The three copies in the National Library collection belonged to the churches of Eid on Ytterøy (D Pal 42), Beitstad (D Pal 43) and Ørlandet (D Pal 44), all located in Trøndelag county. The loose cover without textblock belonged to the church of Gildeskål in Nordland County.

[7] The cover without textblock contains a church inventory from Gildeskål old church probably dating from the early seventeenth century including older references.

Fig. 2 **a** Detail of the sewing structure. **b** Endleaf guards of handwritten parchment fragments in NB D Pal 44

parchment fragments. Smaller parchment fragments were utilised as narrow transverse spine linings and board stabilisers. The parchment fragments (Fig. 2b) in NB D Pal 44 originates from two liturgical music manuscripts from the first half of the twelfth century, containing continental music notation, and a twelfth century Bible; they are all in large format and were probably used in the Trondheim area [15]. These fragments have relevance to early Norwegian book history. Despite the scarcity of preserved materials, these ordinary yet large-format manuscripts serve as valuable documentation of book importation to Nidaros and usage at the archbishop's seat, highlighting Norway's comparatively low preservation rate of such materials, especially considering the early timing concurrent with the establishment of the Norwegian archbishopric [8]. The text is written in three different inks: brown-blackish iron gall ink and red and green inks.

The leather bindings are richly decorated with blind tooling. The bookbinder had access to handheld finishing tools with engraved designs which were in common use elsewhere in Europe and included a pallet with a continuous repeating gothic leaf pattern, a three-line pallet, a plaque with a double pointed arch, a small stamp with a Madonna and child motif and a stamp with rose motif. Each copy with original binding, both those analysed in Norway and those (outside Norway) we have only seen in the digitised version, has an individually designed composition (Fig. 3), which tells us that the bookbinder made ample use of the tools he had available [14].

The books have two clasp fastenings consisting of two rectangular metal catch plates with decorated elements in the form of bevelled edges, grooves and engraved circles located on the fore-edges of the front boards. They appear similar in shape, size and design, but they are not identical. This indicates hand production rather than mass production by casting [16].[8] Traces in the leather cover and preserved rivets on the other boards show signs of similar, but lost catch plates. Bevel stops are carved out under the catch plates to make the board side plain. Metal corner fittings are mainly for protection and without any decorations. Their uneven size and shape indicate that the corner fittings are handmade in situ and not ready-mades.

The textblock in NB D Pal 44 is equipped with altogether six gold-coloured leather tabs fixed to the front edge, to point to central areas in the textblock such as the beginning of the Canon of the Mass.[9] We observed similar leather tab bookmarks in copies belonging to

[8] Archaeological finds in Norway document that book clasps of similar type were in use and manufactured in the 13th to sixteenth centuries.

[9] In the Roman missals the Canon of the Mass – *Canon Missae* – begins on the page that follows the woodcut of the crucifixion.

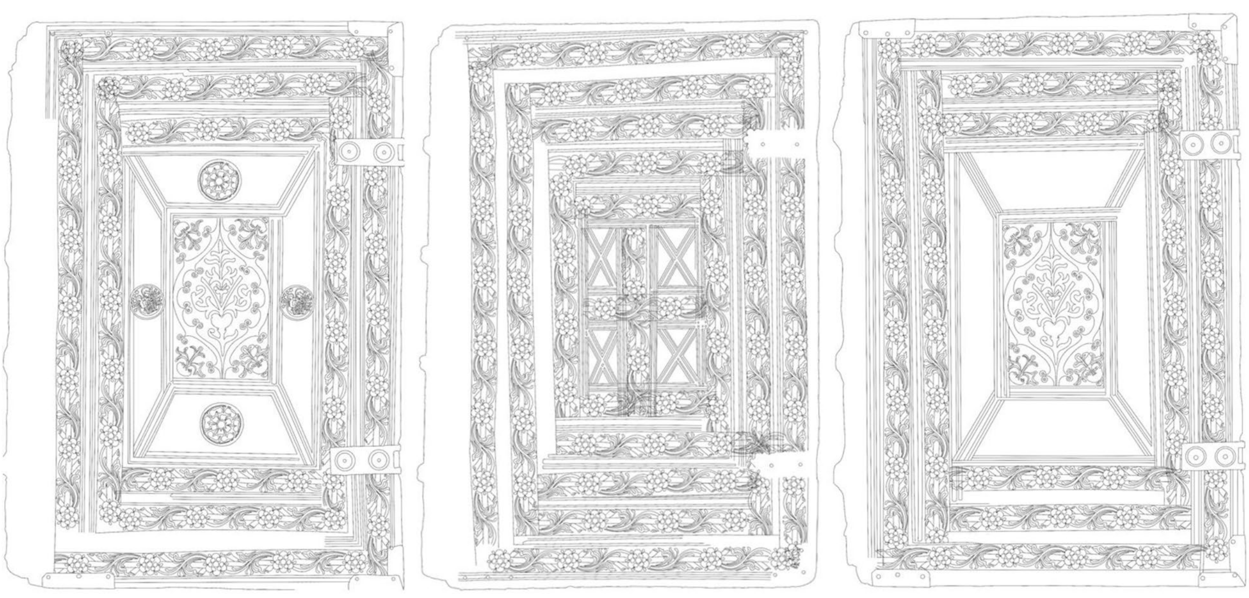

Fig. 3 Blind-tooled decorations on the leather covers (NB D Pal 42, NB D Pal 43, NB D Pal 44)

both Deichman and Gunnerus libraries. Since they vary in type and location and do not occur in all copies, they would not have been standard elements for the original bindings but rather added by request of the owner.

Paper and printing technique

To gain a more precise and complete idea of the origin of the paper used to print the *Missale*, all three book blocks at the National Library and the papers from the other preserved copies in Norway were examined. Considering that there were no paper mills in Denmark/Norway until 1573 [17–19],[10] the paper would have had to have been imported from the large production centres of the period, such as France, Germany or Italy, through Western European trade lines [20]. Watermarks were registered, the distances between the chain lines, and the density and thickness of the laid lines and the average thickness of the sheets were measured. The watermarks' measurements were collected and their position on the sheet mapped to facilitate the identification of the starting paper format. Two watermarks were detected: a small bunch of grapes, or a small flower (Fig. 4a), and a sphere surmounted by the cross of Lorraine (Fig. 4b), which allows the identification of the source for paper for at least a certain number of sheets [23].[11]

The paper is generally of good quality, and variations are often due to manufacturing defects rather than the quality of the paper pulp. Each type of paper was numbered from 1 to 5, taking into consideration their position in the volumes, starting from the title page. The alternation of the different types of paper is practically identical in each volume, and this aspect leaves open many assumptions about the paper supply of *Missale Nidrosiense*. According to several sources, the presence of a very few sheets of a different type of paper, always in the same place in the paper block, may indicate that some leaves, so-called "cancels", had to be reprinted due to correction of errors [18, 21].

By comparison, we observed that the type matters are identical, except for the red initials. The *Missale* is printed in red and black types, based on medieval Gothic handwriting. In both magnification and raking light, it is possible to see the printing sequence of colours, first red and then black (Fig. 6e).

The *Missale* has printed musical staves, while the notes themselves, when present, have been added later by hand. The manual music notations occur in NB D Pal 44 and NB D Pal 42. From the analysis of the inks sequence, it was found that the red lines of the staff were probably applied subsequently to the printing of the text and images. The ink has a different viscosity, which allowed the red ink to migrate through the paper

[10] The first known Danish paper mill was established by Sten Bille in 1573 in Herrisvad cloister (today in the Swedish province of Skåne) and operated for only three years. In 1576 King Frederik II of Denmark established his own paper mill in Hvidøre, north of Copenhagen. The Hvidøre mill closed just a few years later, in 1583.

[11] Viewing and defining characteristics of this watermark is difficult because of the printed text and its size (17 × 10 mm).

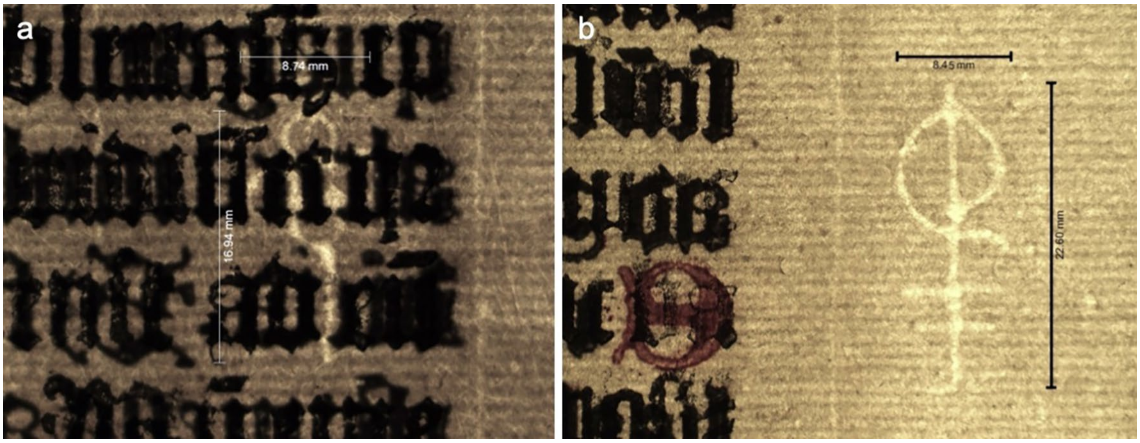

Fig. 4 **a** Watermark showing a small bunch of grapes or a small flower (NB D Pal 42). **b** Watermark showing a sphere surmounted by the cross of Lorraine (NB D Pal 44)

and deposit in conspicuous agglomerates on the opposite side of the sheet (Fig. 6a–d).

The printer, Poul Reff, employed metalcut to make the decorated initials and the coat of arms on the title page [22], while he adopted woodcut for the full-page illustration with the crucifixion of Jesus. The woodblock used for the crucifixion shows signs of wear due to its repeated use in the printing of other editions, certainly for printing the same motif in *Missale Hafniense* in 1510. However, some damage and loss in the woodblock is already apparent in the crucifix woodcut from *Missale Hafniense* (National Library's copy), so the woodblock must evidently have been in use even before 1510. Further information on paper and printing techniques used for the Missale can be seen in Hesselberg- Wang, Palandri [23].

Methods

Visual and multispectral methods

Visual and multispectral methods were implemented to investigate the copies' components, printing technology and bookbinding structure including fibre-identification of the sewing material. Initially, investigations started with a material component analysis of the National Library's three *Missale* and were conducted by the conservators with the use of a stereomicroscope, a portable digital microscope and a multispectral device. The Lynx stereomicroscope (8x–40x) enabled the collection of data relating to leather, paper fibres and inks, while the digital microscope Dino-Lite allowed more in-depth observation and the acquisition of photomicrographs with magnifications up to 250x. The multispectral investigations of paper, texts, illustrations, writing inks and printing colours were carried out in a Foster & Freeman VSC-8000®.

X-ray fluorescence spectroscopy (XRF) and synchrotron-based infrared microscopy

Pigments, printing inks and binders were analysed using a combination of XRF and synchrotron-based infrared microscopy. To investigate the three copies of the *Missale*, X-ray fluorescence spectroscopy (XRF) was applied to determine the elemental composition of inks and metals present in the books. The analyses were carried out by means of a handheld Bruker Tracer 5 instrument. The measurement spot had a diameter of 8 mm, in some cases it was reduced to 3 mm. Internal calibration, implemented into the instrument by the manufacturer, allowed semi-quantitative measurements.

To examine organic compounds, samples were taken from preferably spots where slight damage had already occurred. A spatial resolution down to 5 µm and a high signal-to-noise-ratio provided by synchrotron-based infrared microscopy allows to study the internal structure of very small but heterogeneous samples [24, 25].

The measurements were carried out using a Nicolet Continuµm Infrared Microscope (Thermo Scientific) coupled to a Nexus 870 FT-IR spectrometer at the IRIS infrared beamline at the BESSY II electron storage ring operated by the *Helmholtz-Zentrum Berlin für Materialien und Energie* [26]. Samples were measured in transmission mode through a diamond compression cell using 32 × magnification and numerical aperture NA = 0.65 infrared reflective objectives, and a liquid nitrogen-cooled mid infrared MCT detector. Both single point measurements and mapping experiments were performed using 128 scans per measurement with aperture sizes—which defines the size of the measuring spot—between 5 × 5 and 12 × 12 μm^2.

Non-invasive dendrochronology based on X-ray tomography

To indicate the felling date and provenance of the books' oak wooden boards, non-invasive dendrochronology based on X-ray tomography was utilised. Dendrochronology is the analysis of the pattern of wide and narrow rings in trees: the tree's annual growth is like a fingerprint of the climate in the place and time that the tree grew.

In Northern Europe, oak (*Quercus* sp.) has been one of the major timber genera that has been the object of these analyses. Extensive dendrochronological data sets for oak across Europe now allow precise dating and provenance identification of historical timber, and we see the varied patterns of timber exploitation [27]. From around 1350, for example, we observed the appearance of oak from the regions to the east and south of the Baltic Sea in Western Europe. This so-called Baltic oak is found extensively used as panels and boards as supports for artworks, for ecclesiastical furniture and art, as panelling in buildings and for making barrels etc. [28–30]. In the 1980s the large tree ring data sets from these various objects were identified as stemming from the Eastern/Southern Baltic [31, 32].

In the extensive corpus of dendrochronologically analysed oak, from the *c.* fifteenth to the seventeenth centuries, used as supports for fine art and for ecclesiastical sculpture, it is possible to distinguish between different groups of the Southern Baltic timber (named Baltic 1, Baltic 2 and Baltic 3), and these groups most probably represent forests in different areas within the region [33]. New research is allowing us to identify the areas these groups came from [34]. While we also have evidence of past exploitation of timber from other regions to the consuming centres of European economic growth, the Baltic groups of traded timber are particularly to be kept in mind in the context of the results of the analysis of the book bindings here.

Non-invasive dendrochronological analysis has proved successful in recent years, both through CT-scanning of oak objects and, when possible, through analysis of exposed tree-rings on objects [35–37]. Through several analyses using the installation in the Norwegian Geotechnical Institute (NGI) in Oslo, a standard protocol has been developed by the authors on objects of suitable size. The four books were CT-scanned to gain access to the tree rings of the oak bookbinding boards: Hereafter referred to as book 1 (loose cover without textblock, Ms.fol. 3858), book 2 (NB D Pal 42), book 3 (NB D Pal 43) and book 4 (NB D Pal 44). Since the date of the production of the books was already well known, the main objective was to establish the provenance of the oak used in the binding of the books.

In order to obtain tree ring measurements for analysis, the books were placed upright on a stand made of medium density fibreboard (MDF) without metal parts (Fig. 5a). The books were positioned in the scanner in such a way as to optimise the resolution and to enable the maximum number of tree rings to be visible. The X-ray settings used for the books were similar to those used in previous studies [35]. We used 80 kV and 120 uA X-ray settings and a 0.1 mm copper filter. The object rotates slowly, and about a thousand X-ray images are produced from different angles. These are compiled into a 3-D model of the X-ray attenuation throughout the object with a voxel size of approximately $0.050 \times 0.050 \times 0.050$ mm. Virtual cross sections of the object (Fig. 5b) can then be extracted for tree ring measurement. Measuring was carried out from these images using the programme Able Image Analyser, and for the analysis and the calculation of the t-value ("t-test"), the programmes "DENDRO" and "CROS" were used [38, 39]. An extensive network of master and site chronologies for Northern Europe were consulted to find the dating for the tree ring series.

Biocodicological analysis

Both parchment and leather, made from animal skins, were used in the books. In order to determine the species of animals used for these materials, we applied proteomic analysis through a biocodicological approach [40]. Non-invasive eZooMS (Zooarchaeology by Mass Spectrometry) analysis was carried out on nine parchment samples and three samples of the leather binding of the books. The full method and details of the protocol can be seen in Fiddyment et al. [41]. Briefly, the surface of the leather and parchment were gently rubbed using pieces of PVC eraser, that allows the collection of collagen fibres for species identification. The resulting eraser crumbs were incubated in a saline solution and the extracted collagen digested using trypsin. The resulting peptides were then measured using mass spectrometry and the resulting data was analysed using a peptide reference database for species identification.

Results and discussion

Visual and multispectral methods

Transmitted light and raking light were essential tools to facilitate the study of surfaces and structures. The possibility of altering the composition of light waves from 265 to 1000 nm in combination with different colour filters revealed otherwise hidden features and visualised new knowledge. The option to utilise colour absorption and colour reflection filters facilitates the identification of handwriting and printing techniques by making them appear more distinct and even visualising the order

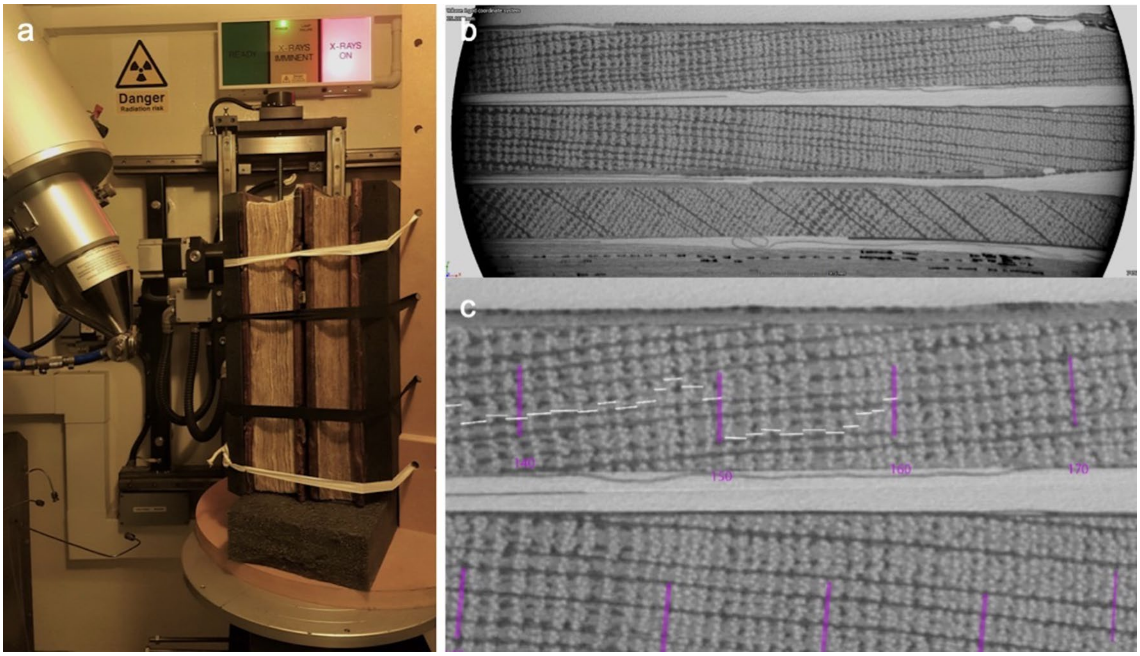

Fig. 5 **a** Position of the books for scanning. **b**, **c** Virtual cross sections of the books

of media application. Irregularities appeared during the study of every single sheet of paper in VIS (Visible Spectrum) transmitted and raking light such as printing errors, corrections and page layout errors. Some of these were covered by glueing strips of paper with the printed corrections (Fig. 6f). These are usually located in the same areas in all three *Missale*, with some exceptions.

Prior to the identification of the fibres, a hypothesis is based upon our knowledge of the tradition of bookbinding, that the fibres used in NB D Pal 42 and NB D Pal 43 could be either flax (*Linum*) for sewing thread [42][12] or hemp (*Cannabis*) for sewing support. Both hemp and flax fall into the category of 'bast' as the fibres are similar and can sometimes be only identified as a group contrary to the exact fibre used [43]. The availability of different fibrous materials must also be considered: despite flax being a common choice, hemp was grown in Norway [44] and therefore being an accessible option. Whereas flax fibres are longer, hemp has been used due to its higher breaking force in contrast to flax, therefore providing longevity for the binding [45]. Additionally, the threads could have been treated with beeswax, as this would have made the thread stronger and enabled it to glide through the holes easier for facilitating the sewing. For this study, detection of any additional treatment as this of the fibres was kept as an additional research objective when observing the fibres.

For identification, samples from the sewing support and sewing thread of NB D Pal 42 and NB D Pal 43 were carefully taken. After sampling, the threads were separated to their individual fibres and mounted in silicone oil for longitudinal observation with light microscopy as a simple way to identify the fibres based on their morphological features [43, 46] with magnifications of 40× and 100× used. The identification of historical fibres can be challenging considering the exposure to dirt and distortion the fibres undergo through time, and malformation can occur even during the initial manufacturing of the threads and from the use of the book [43]. With the challenge of differentiating hemp from flax as the fibres carry very similar features [43, 47], the characteristic nodes of the flax and hemp [43] were used as the discriminating factor between the two. Modern and historical fibre references were used to confirm the identification.

As a result, it could be concluded that the NB D Pal 42 and NB D Pal 43 both had flax as the sewing thread and hemp as the sewing support, following the earlier hypothesis based on traditional bookbinding. Some of the fibres showed microscopic marks of a dark yellow coloured material, which could possibly be beeswax or some other adhesive material from the construction o]]]] r the use of the book, such as animal glue.

[12] Linen thread made from flax is a resistant fibre, enduring the practice of pulling in sewing. Sewing supports have been made from various materials such as parchment, paper, leather and cord.

Fig. 6 **a**–**c** Migration of red ink through the paper in VIS (**a**), raking light (**b**) and infrared fluorescence (**c**). **d** Detail of the agglomeration of the red ink. **e** Magnified image of the printed text, showing that the printing sequence was first red, then black. **f** An error in printing has been corrected with a slip of paper

Dendrochronological analysis of the book bindings

Book 1 (loose cover without textblock, Ms.fol. 3858)

The two boards of book 1 were no longer attached to the book, so these could be placed alongside book 4 for the scanning. The scans did not quite reach the full width of the boards, so an unknown number of inner and outer tree rings are not measured or counted. Both boards are radially converted from the parent tree. Board 1 (Z256004a) has 213 measured rings, while board 2 (Z256003a) has 230. The correlation between the tree ring curves of these two boards is so similar, both statistically ($t = 16.93$. Table 1) and visually, it is most probable that they are manufactured from the same tree. The tree ring curves are dated. The outermost measured tree ring is on board 2, and it was formed in AD 1476. No remains of sapwood were observed. Allowing for missing sapwood, using a sapwood average for Northern Poland (15 years (− 6 + 9)) [29], we can estimate that the tree for the two boards for book 1 was felled after AD 1486, and certainly later than this as we have an unknown number of rings that were not visible on the virtual cross section.

Book 2 (NB D Pal 42)

The two boards of book 2 were scanned alongside book 3. The scans reach the outer edge of both boards, but no sapwood is observed. Both boards are tangentially converted from the parent tree. The back board (Z2560069) has 125 measured rings, while the front board (Z256008a) has 198. The tree ring curves are dated. The outermost measured tree ring is on the front board, and it was formed in AD 1452. Allowing for missing sapwood, again using the North Polish sapwood statistic, we can estimate that the tree for the back board was felled after AD 1452, while that for the front was felled after AD 1462 (see Fig. 7).

Book 3 (NB D Pal 43)

The two boards of book 3 were scanned alongside book 2. The scan of the front board (Z256005a) reaches the outer edge while that of the backboard (Z256007a) just misses the very outer edge. No sapwood is observed. Both boards are tangentially converted from the parent tree. The front board has 213 measured rings, while the back board has 212. The correlation between the tree ring curves of these two boards are so similar, both statistically ($t = 15.53$. Table 1) and visually, it is most probable that they are manufactured from the same tree. The tree ring curves are dated. The outermost measured tree ring is on the front board, and it was formed in AD 1479. Allowing for missing sapwood, we can estimate that the tree for the two boards for book 3 was felled after AD 1489 (see Fig. 7).

Book 4 (NB D Pal 44)

Book 4 was scanned alongside the two loose boards of book 1. The scans do not reach the outer edge of these boards. No sapwood is observed. Both boards are tangentially converted from the parent tree. The back board (Z2560019) has 196 measured rings, while the front board (Z256002a) has 158. The tree ring curves are dated. The outermost measured tree ring is on the back board, and it was formed in AD 1410. Allowing for missing sapwood, we can estimate that the tree for the back board was felled after AD 1420, while that for the front was felled after AD 1410 (see Fig. 6).

The tree ring curves from the boards from the four books crossmatch with each other as shown in Table 1. A strongly correlating group can be defined, including seven boards representing five trees (highlighted in blue). These are averaged to form a mean curve (Z256M001) of 241 years in length. In Table 2 the correlation values (*t*-values) between this average curve and a selection of Northern European chronologies are shown. This information is also mapped (Fig. 8). The material is dating strongly with Southern and Eastern Baltic oak tree ring data sets. Particularly high *t*-values are achieved with the Baltic1 art-historical group, mentioned above, indicating that the oak used for the bookbindings belong to the same trade network as materials for painted panels. The *t*-values listed include correlations with the older Baltic1 chronology [33] and the new, more deeply replicated version [34]. Recent analysis of the art-historical dendrochronological groups indicates that this Baltic1 group represents oaks that grew in the lower Nemunas River that flows into the Curonian Lagoon [34]. The book boards also achieve a strong *t*-value with a recently built chronology for oak from Klaipeda [49]. It seems clear that the source of the oaks for the *Missale* bindings was Western Lithuania where it would have been transported to the coast and perhaps shipped from the flourishing trading town of Memel (now Klaipeda).

The backboard from book 4 (Z2560019) falls outside the clear group (highlighted with green in Tables 1 and 2). This board is also dating with Southern and Eastern Baltic data sets, but it might be from a tree that grew in a different area to the trees in the main group.

In terms of the wood used for the bookbindings, the resulting dating and the high agreement between many of the boards used indicate that the majority of the boards belong to a homogeneous group. Perhaps the blue group represents a single shipment. Also, the board that does not belong with the main dendrochronological group is dating with chronologies from the same region as the main group. This particular board is shaped using the inner part of the tree, close to the pith, and the juvenile growth in this particular board might be the reason we

Table 1 *Missale Nidrosiense*. Result of the correlation (*t*-value) between the tree-ring curves from each board with each other

				Z2560019	Z256002a	Z256003a	Z256004a	Z256005a	Z256007a	Z2560069	Z256008a
		Book 4 back	Z2560019	*	2.66	2.94	2.44	3.43	3.88	3.66	1.04
Average **Z256M001**		Book 4 front	Z256002a	2.66	*	5.97	5.79	6.92	6.28	5.83	3.81
	Same tree	Book 1 p2	Z256003a	2.94	5.97	*	16.93	5.91	7.68	6.73	4.02
		Book 1 p1	Z256004a	2.44	5.79	16.93	*	7.06	7.17	7.16	5.13
	Same tree	Book 3 front	Z256005a	3.43	6.92	5.91	7.06	*	15.53	7.11	6.54
		Book 3 back	Z256007a	3.88	6.28	7.68	7.17	15.53	*	6.8	7.35
		Book 2 back	Z2560069	3.66	5.83	6.73	7.16	7.11	6.8	*	7.42
		Book 2 front	Z256008a	1.04	3.81	4.02	5.13	6.54	7.35	7.42	*

Book 1 (loose cover without textblock, Ms.fol. 3858), Book 2 (NB D Pal 42), Book 3 (NB D Pal 43) and Book 4 (NB D Pal 44)

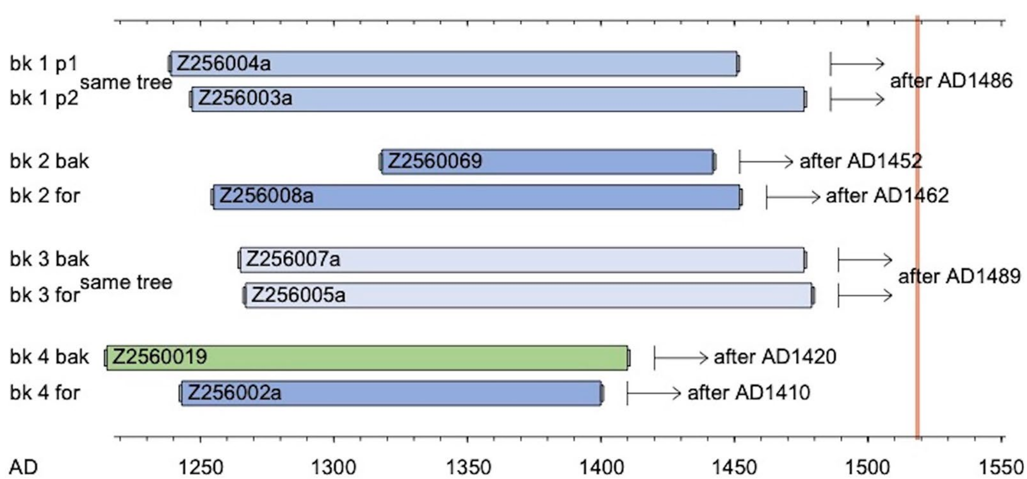

Fig. 7 Results of the dendrochronology of Missale Nidrosiense. The diagram illustrates the chronological position of the dated wood elements. The blue and green shading corresponds to the highlighting in Tables 1 and 2. The orange vertical line marks the date of the printing of the books—AD 1519

achieve a less strong correlation. When we see that both boards in two of the books come from the same tree, we might envisage that the raw material was a longer board that the bookbinder sawed into two identical halves, or that a thicker board was sawn to two thinner ones. The two boards of book 2 are also very similar to each other, but the dendrochronology does not unequivocally allow us to suggest that they are from the same tree, although this cannot be ruled out. Looking at the conversion of the boards from the parent tree, it appears that the boards are quarter-sawn. In other words, the procedure after felling the tree was to divide the log, probably by splitting, in half and then quarter. Then parallel planks could be sawn from each quarter. In this way some boards have rings almost exactly perpendicular to the board edge (book 1), while in others the rings are in a diagonal

Table 2 *Missale Nidrosiense*. Result of the correlation between the average curve Z256M001 and the tree ring curve Z2560019 and diverse Northern European site and master chronologies

Filenames	–	–	Z2560019	Z256M001	
–	Start	End	1215–1410	1239–1479	
Site and master chronologies					
2021BLT1B	AD1181	AD1527	6.99	12.68	2021 Baltic1, Bowhill-Vejdyb type, 81 trees [48]
klaipeda-oak	AD1247	AD1552	4.14	11.09	Klaipeda [49]
2021BLT1	AD1143	AD1626	7.55	10.07	2021 Baltic1, 552 trees [48]
BALTIC1	AD1156	AD1597	6.74	9.91	Baltic 1, 64 timbers [33]
Memel Klaipeda	AD1288	AD1580	–	7.44	Memel, Klaipèda [50]
P802001m	AD1209	AD1401	–	6.14	Poland, Krupy [51]
vilnioak	AD1202	AD1530	3.73	6.02	Vilnius Castle oak 20 timbers [52]
PP111M01	AD1136	AD1399	–	5.92	PL Gdansk St Nikolaus 11 timbers [51, 53]
StJM2	AD1342	AD1514	–	5.86	St Jakobs Church Riga 12 timbers [54]
PP106M01	AD1110	AD1399	–	5.76	PL Gdansk Parc.6 14 timbers [51, 53]
P676001m	AD1084	AD1393	–	5.61	Poland, Kolobrzeg [51]
0628002 M	AD1225	AD1445	4.70	3.45	Torun Joh. K. [51]
2021BLT3	AD1292	AD1645	4.04	3.34	2021 Baltic3, 280 trees [48]
Ship chronologies					
Z2261M01	AD1098	AD1522	8.85	8.53	Køge ship, planks, 18 timbers [55, 56]
Z2261M03	AD1264	AD1537	5.09	7.47	Køge ship, double planks, 7 timbers [55]
00751M01	AD1113	AD1463	7.56	6.96	Vejdyb ship, 14 trees [57]
Z084M001	AD1152	AD1437	4.12	6.15	Skaftö wreck, barrels, 9 timbers [58]
Chronologies from Baltic exports					
stirlingdoorsM1	AD1270	AD1524	3.16	8.21	Stirling Castle, doors, 10 timbers [59, 60]
H11EOM01	AD1260	AD1495	5.20	7.06	Bordesholmer Altar, 10 timbers [53]
Z002M002	AD1121	AD1391	–	5.79	Avaldsnes cog, Norway 4 timbers [61]
Z054m001	AD1235	AD1448	5.76	5.46	Ostsee VII planks, 5 timbers [62]

The source of the chronologies is given

position. The homogeneity of this material could allow us to suggest that the timber that was transported to the workshop where the bookbinding took place was in the form of oak quarters.

The provenance of the wood does not indicate where the binding of the books might have taken place. It is a period where we see extensive trade of Baltic timber to Western Europe, especially of long, straight boards and planks of knot-free oak. The material evidence of this trade, which we can readily identify as being from the Southern and Eastern Baltic region through dendroprovenance, is almost without exception in the form of planks, boards, wainscots etc., not bulky scantling. The homogeneous oak group we see used for *Missale Nidrosiense* shows us that either quarter logs were indeed shipped westwards for reduction to planks or boards in Western Europe, or the boards that were sawn in the Baltics were shipped as homogeneous packages which did not spread to different users, at least in this instance. The evidence certainly suggests that these four books were bound in the same workshop.

X-ray fluorescence spectroscopy (XRF) and synchrotron-based infrared microscopy

Missale Nidrosiense is printed with black and red ink. XRF measurements of the black ink gave no hints as to any significant iron content; therefore, it was concluded that a carbon black ink was used. XRF spectra of the red printing ink showed peaks corresponding to mercury and sulphur. No signals related to lead were observed, indicating that the red ink was made from pure cinnabar without any admixtures of *minium* (red lead oxide). The latter was frequently used to give the colour a lighter hue.

Particles from both the red and black ink were examined by infrared spectroscopy. The spectra reveal a gum, probably *gum arabicum* (Fig. 9) which was used as binding medium in both types of ink. Several spots of the same sample have been measured, all of them showing the same spectrum and proving that the material is homogeneous and does not contain any admixtures.

It was possible to access the edge of a parchment placed under the leather cover of *Missale* D Pal 44 used as a strengthening material. Some letters written

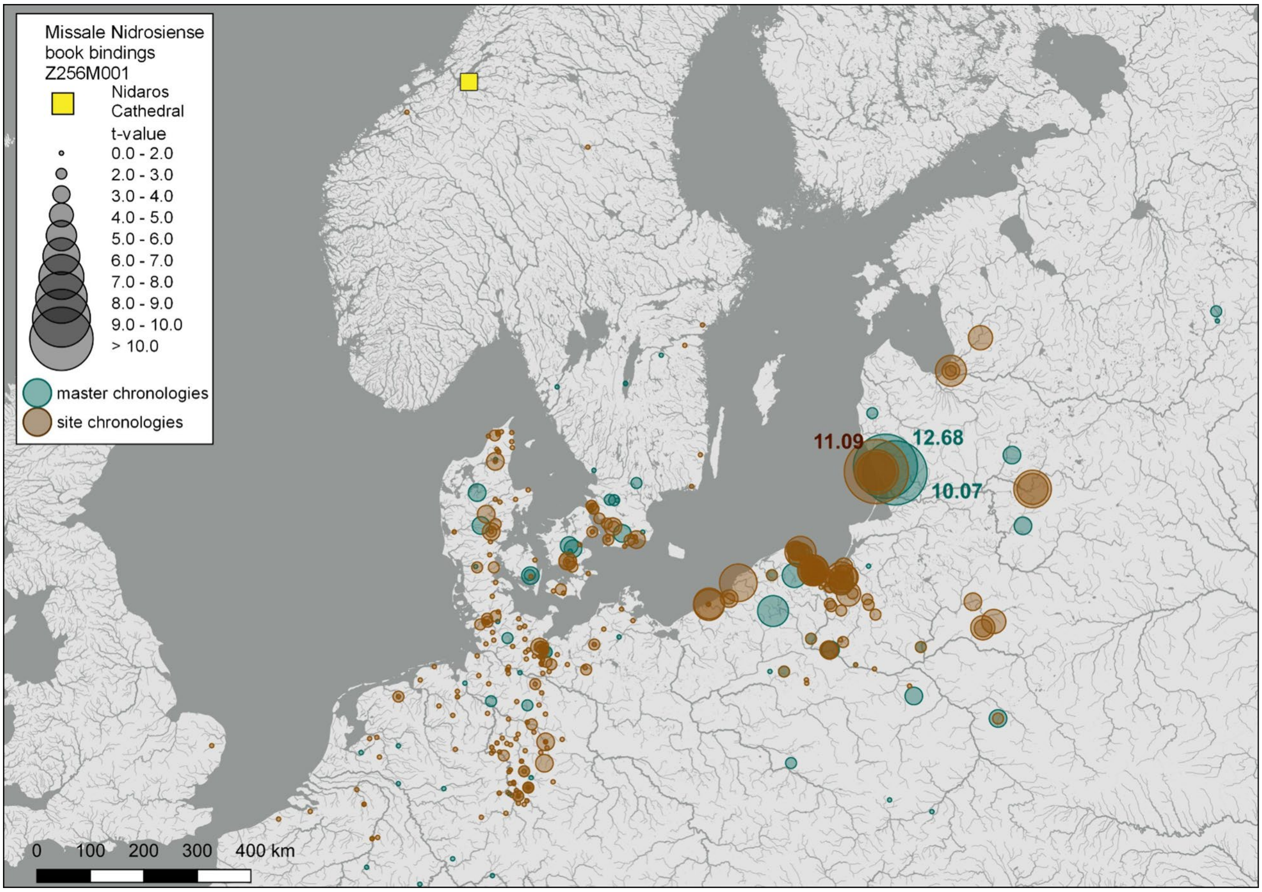

Fig. 8 Map showing the distribution of the correlation between the average chronology for the book covers and site and master chronologies for oak in Northern Europe. The underlying tree-ring dataset is described in Daly (2007) but recent additions to this dataset for Lithuania, Latvia and Russia are added. The background map is from the Global Administrative Areas project (gadm.org) https://geodata.ucdavis.edu/gadm/gadm4.1/work/ Downloaded 10 January 2023. The river data is from Lehner and Grill (2013) (www.hydrosheds.org, accessed March 3, 2020). The map is generated using QGIS.org, 2021. QGIS Geographic Information System. QGIS Association. http://www.qgis.org

in green and red ink respectively could be analysed by XRF, and some small samples could be taken to conduct infrared measurements. XRF analyses identified the red ink as cinnabar, whereas the green contained copper. The infrared analyses gave indications that the green compound is verdigris. The letters were covered with a transparent coating which was identified as a cellulose compound. At the binding a brownish adhesive was identified as a proteinaceous material, indicative of animal glue.

Several bookmarks are present in NB D Pal 44 made of gilded leather (Fig. 10b), and we analysed the one at pages 263–264. Three layers of the gilding can be identified: a shiny metallic one, a red one and as the upper layer a yellowish one (Fig. 10c). An XRF measurement reveals Ag, Cu, Fe, Hg and some As (Fig. 10a). It is assumed that the metal strip is made from a silver copper alloy covered with cinnabar. The iron, in the form of its oxide or hydroxide, may form a red or yellow pigment, whilst arsenic is part of an orange or yellowish arsenic sulphide. The silver strip is covered with a resin, which was verified through infrared analysis. Since different types of resins are hard to distinguish by infrared spectroscopy, a detailed determination of the type of resin would require a technique such as gas chromatography. The metal furniture (cover clasps, corners and fittings) consists of a brass alloy containing ca. 80% copper, 19% zinc and 1% lead.

Biocodicological analysis

All nine parchment fragment samples were identified as calf through ZooMS analysis. Of the nine, two samples taken from the spine also presented sheep markers, however this could be attributed to contamination from animal glue due to the location of the sample. Furthermore, the visual inspection and knowledge on parchment production supports the parchment to be of calfskin [64] ZooMS was also employed to confirm the species of the

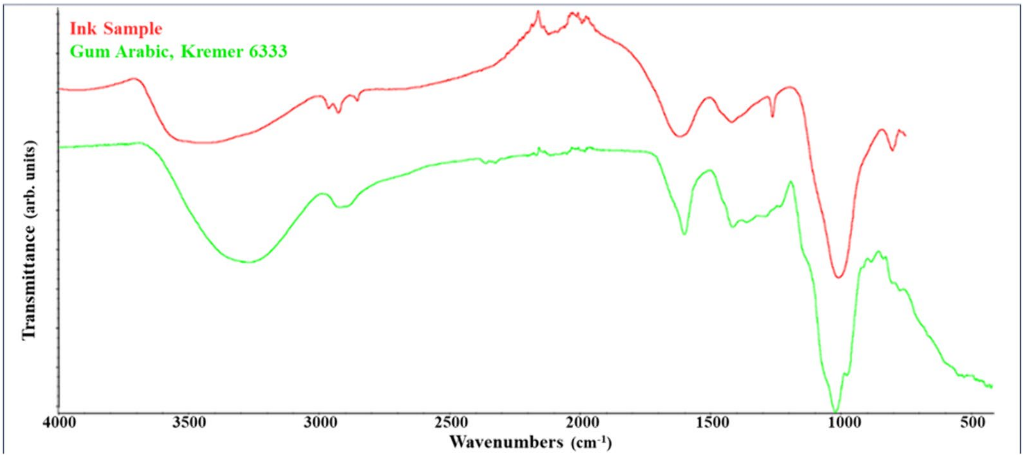

Fig. 9 FT-IR spectrometer measurement of an ink sample (in red) compared with a reference spectrum of gum arabic (in green). The region 2600–1668 cm^{-1} contains diamond absorbance from the compression cell. Spectra are shifted for clarity

leather covers. Unfortunately, only one sample of the leather covers yielded enough collagen for ZooMS, the sample from Ms.fol. 3858 (loose cover without textblock). The analysis indicated that the leather came from either sheep or goat skin, but due to the quality of the collagen, the differentiation of these two was not possible.

Each species of animal has a unique hair follicle pattern, but due to the excessive working of the skins when producing leather or parchment, the hair follicle pattern may be distorted or lost, making the identification difficult or impossible [63]. The hair follicle pattern from the leather covers was quite challenging to recognise, partly because the holes were filled with leather dressing due to previous conservation treatments.[13] Despite this, it could be determined that the leather covers were made of sheepskin based on the observation of the hair follicles (Fig. 11a, b), especially from the inside of the leather covers.

Both calfskin for parchment and sheepskin for the leather covers match well the traditions in bookbinding employing the skins of different animals based on their qualities [65].

Conclusions

Traditionally, historical book research in Norway has mainly been aimed at textual content. In our research we wanted to explore how in-depth analyses of the books' characteristics, with an emphasis on materials and techniques used, would yield new and interesting knowledge about the biography of the books. Our primary objective was to examine each component of the book separately to achieve a comprehensive description and comprehension of a singular, multi-material object. Secondly, our aim was to study whether and how an archaeometric approach with scientific analyses of the various constituent parts of the book could uncover evidence relating to the dating and origin of the materials. On the other hand, our results confirm previous knowledge, and whereas our study also identifies the potential limitations of certain methodological approaches, this level of "basic" analysis is essential also from the viewpoint of authentication and attribution for the *Missale Nidrosiense*. Additionally, this information is essential for the preservation and conservation of these rare artefacts.

The study of the use of paper, its quality, provenance and availability in Copenhagen in the first quarter of the sixteenth century, has provided fresh information. The examination of ten preserved copies of *Missale Nidrosiense* and the identification of an identical pattern offers a more precise understanding of the preliminary phases leading up to the actual printing process. Likewise, the bookbindings' execution and selection of materials bear witness to deliberate and intended "serial" production. The X-ray analyses of pigments, inks and metal components revealed rather standard formulas expected from the industry of bookmaking. These are from a use-perspective challenging to connect to a particular producer, area or region: trade for cinnabar and arabic gum for manuscripts was already well-established before printing developed. Furthermore, the fibre identification of the sewing support and thread revealed the use of traditional bookbinding materials utilised 'everywhere'. As expected, the parchment fragments were calfskin following Scandinavian parchment production

[13] The National Library implemented a leather dressing scheme in the early 1980s recommended by the British Library. The dressing named *Pliantin* (a mix of beeswax, cedar oil, lanolin and hexane) was applied to a large amount of leather bindings.

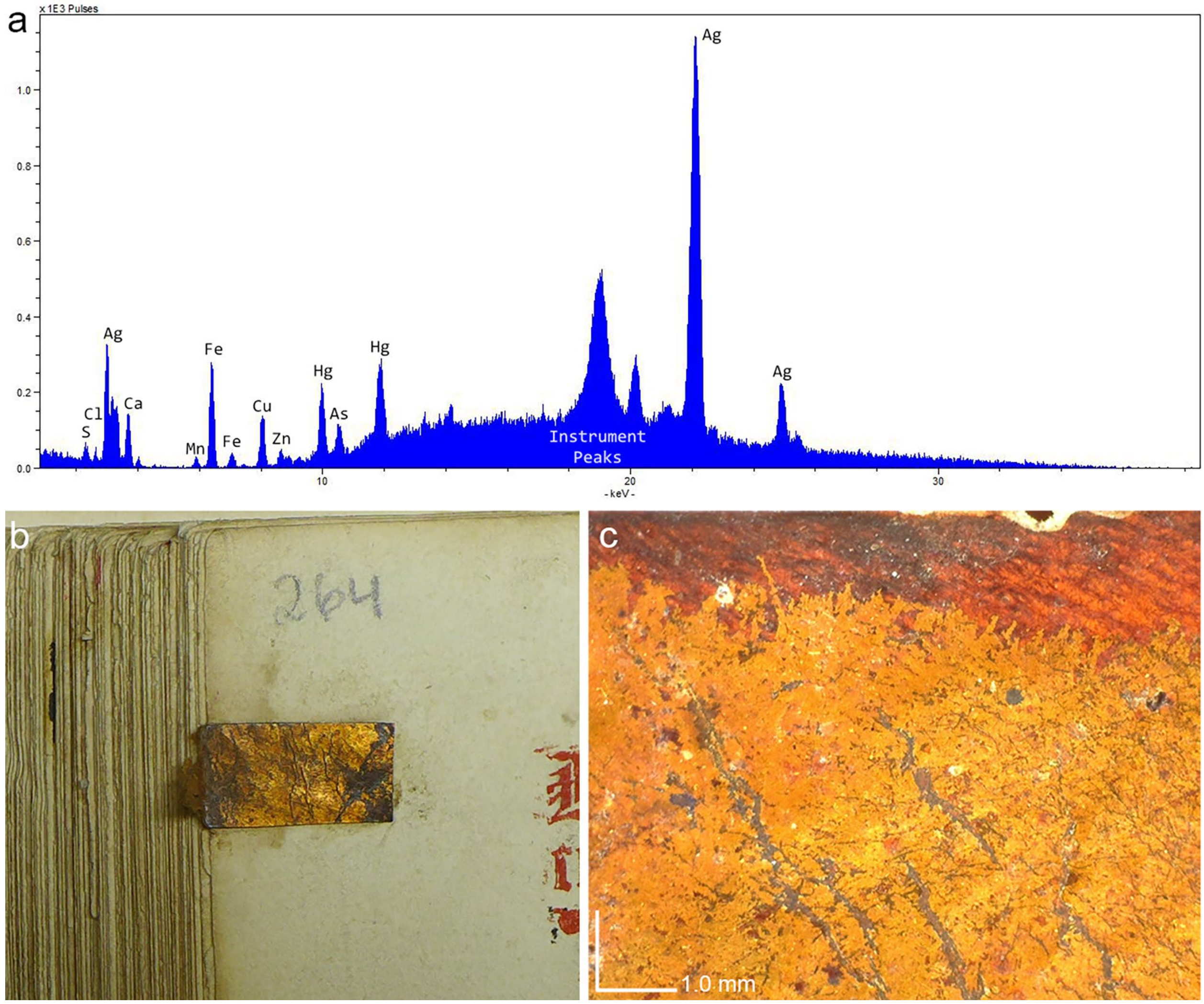

Fig. 10 **a** XRF spectrum of the bookmark shows a high content of silver, a smaller portion of copper and peaks related to iron (containing some manganese), mercury, and arsenic. **b** The bookmark, pages 263–264 of NB D Pal 44. **c** Close-up image showing the red and yellow preparation layer

practices and the cover material was confirmed to be tanned sheepskin as per custom in bookmaking.

The dendrochronological analyses of the wooden boards of the bookbinding, offered exciting results in that this analysis was carried out wholly non-invasively and highlighted the highly professional production and trade of oak especially produced for artistic purposes from the regions to the east and south of the Baltic Sea to Western Europe. The use of imported oak over local wood sources reflects a deliberate choice, but also the economic means available to purchase. Archaeological finds of shipwrecks along the Norwegian coast, shown through dendroprovenance to be of Baltic oak, confirm that this timber source was reaching Norway from the second half of the fourteenth century and indicate a well-established trade connection [66].

Despite our work so far has identified a pool of information to establish a starting point for similar studies, it also shows where such investigations could be taken in the future on similar materials. Ancient DNA-analysis of the sheepskin could be helpful in potentially identifying local lineages, if present. This could be combined with stable isotope analysis for grazing, i.e. the environment of the animal during its lifetime. Among Norwegian book historians, an agreement prevails that *Missale Nidrosiense* was bound in Trondheim by the archbishop's bookbinder [14].[14] This is based on the fact that Nidaros archdiocese produced documents in religious, legal and

[14] Astrid Schjoldager suggests 'Casper bookbinder', who lived and worked in Trondheim at the time, but there are no further references to whom he might have been working for.

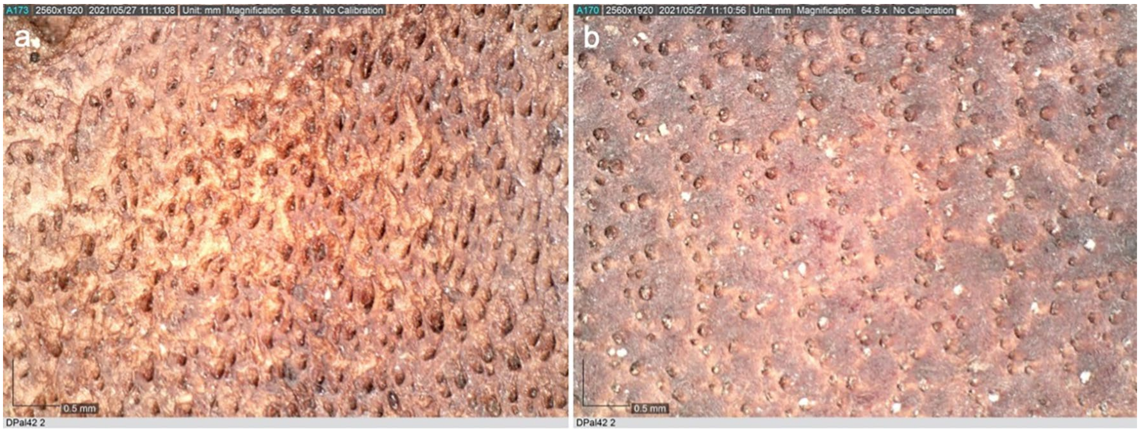

Fig. 11 **a**, **b** DinoLite photographs (magnification × 64.8) of the hair follicle pattern (sheep) observed from the inside of the leather covers of NB D Pal 42

historical categories that were bound on the premises and that handwritten parchment fragments used to reinforce the bindings originate from Norwegian monasteries [67, 68].

To conclude, there is no doubt that more knowledge of the provenance of the materials may provide new information about craftsmanship, economy, trade and commercial exchange in a certain timespan, despite the lack of written documentation from the period. All in all, production of books represented a significant investment, and that reflects the economic power of Nidaros archdiocese at the beginning of the sixteenth century.

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Author contributions
The author's contributions were as follows: CP led the overall paper, conducted historical analysis on materials, contributed to the methodological design and helped to write the paper. TK contributed to analysis, reporting, writing, to the overall study and made the figure plates. AD performed the dendrochronological analysis, data interpretation and reporting, helped to illustrate and write the paper. NH-W conducted historical analysis, contributed to the methodological design and helped to write the paper. HDW and JB aided with the dendrochronological analysis. JV conducted the visual analysis of the hair follicle patterns. LP and HK performed analysis on materials, analysed, reported results and helped to write the paper. SF conducted the proteomic analysis. MJC helped to write the paper and contributed to the design of the study. The final manuscript was read and approved by the authors.

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Availability of data and materials
Reference datasets are cited within the article in the appropriate sections. Derived data supporting the findings of this study are available upon request.

Declarations

Ethical approval and consent to participate
Not applicable.

Consent for publication
All co-authors consent.

Competing interests
The authors declare that they have no competing interests.

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