THE HISTORICAL SIGNIFICANCE OF RESEARCHING THE TECHNOLOGICAL DEVELOPMENT OF EUROPEAN PAPER WITH AND WITHOUT WATERMARKS

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ABSTRACT

Papermaking spreads from the Iberian Peninsula to the surrounding countries, where new tools and technology is developed in Italy to increase the production. In Fabriano Arabian starch sizing is replaced by gelatine sizing, hand pounding of the rags by stamping mills and moulds with loose screen of reeds by fixed metal wire screens with watermarks. Julius Wiesner registers through microscopic analysis of Arabian and European paper these data. In my analysis of the development of European and early Danish paper with and without watermarks I have followed in Wiesner's footsteps by observation of the condition of the rag fibres and the traces of tools and technology used. Without watermarks information about the provenance of European paper is missing, but all other data about the fibre materials and the technology used are to be found through macroscopic & microscopic analysis of the paper.

KEYWORDS

Paper analysis, traces of technology, sizing materials, fibre conditions, writing & printing paper

Introduction

With my background as paper conservator since 1980 at the Conservation Department of the National Museum in Denmark I have worked with paper objects from the Ethnographic collection as well as from the European collection. This is the reason for my deep interest in paper history and continued studies of the technological development of the art of papermaking. Through studies of the very paper I have experienced that much information is to be found from the condition of the fibres about the origin of the papermaking fibre materials and about the technology used. European handmade paper has until the 19th century consisted of recycled textile fibres, and the papermakers have during these centuries adapted their technology to the demands for various paper qualities.

The development and spread of rag paper production

Papyrus and parchment served as writing materials in Europe, when Arabian papermakers in the 12th century introduce their production of rag paper to the Western world on the Iberian Peninsula in Xàtiva. The new writing material and the papermaking craft spread from Spain to Sicily, Southern France and Italy in the 13th century, where the papermakers in Fabriano develop a more efficient European technology [1]. It results in a stronger and better quality of rag paper than the Arabian one, but the Italian papermakers not only change the whole preparation process in breaking down and dissolving the worn-out textiles into individual fibres. They also change the mould and sheet formation techniques in order to increase the production. This new technological development of the papermaking craft in Fabriano spreads during the next centuries to the rest of the countries in Europe, Scandinavia and Britain [2].

First analysis of paper

Rag paper of fibres from recycled flax (*Linum usitassimun, Linaceae* family) and hemp (*Cannabis sativa, Moraceae* family) has until the end of the 19th century been considered as a 12th century European invention quite different from the Arabian paper of fibres from cotton (*Gossypium species, Malvaceae* family). But Julius Wiesner, the Austrian professor in botany and plant anatomy proves in 1887 with microscopic analysis of Arabian manuscripts from the Archduke Rainer's Collection in Vienna that the Arab papermakers have used recycled flax and hemp materials since the 10th century for their paper production [3]. He demonstrates with this first scientific analysis of paper, based conclusively on microscopic examination, spot tests and by using historical criteria that cotton paper has never existed. Both Arabian and European papermaking start with the production of rag paper originally developed in China [4].

Some of the Arabian codices analysed in Vienna 1887 by Wiesner is now kept in the Oriental and Judaic Collection at the Royal Danish Library in Copenhagen, where I have had access to make macroscopic observation of the manuscripts and collect minor samples for microscopic analysis. Scanning Electron Microscopic (S.E.M.) photo of the 12th century Codex Arab 135 informs about a random fibre distribution of flax fibres of even width, mixed with more irregular hemp fibres with the characteristic longitudinal striations and splits. The presence of lime particles originates from the Arabian preparation process of the rags and not from a coating of the paper. By Polarisation microscope (P.O.L.) it is possible among the fibres to observe the presence of starch grains that originates from the starch sizing after-treatment of the paper of Codex Arab135 to make it fit for writing with ink and pen. As illustrated with the S.E.M. observation of Codex Arab 266 from the Royal Library a heavily sizing of the paper surface is needed for the Arabian pen and ink writing tools of similar quality as used for their parchment manuscripts and codices.

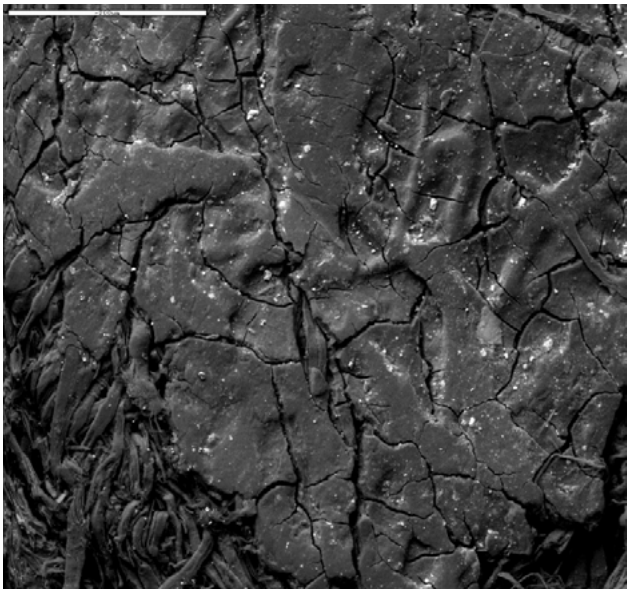

Fig.1 Codex Arab 266, Royal Library, p. 14, heavily sized

A nearly 3-dimensional impression of the morphology and surface of the individual flax fibres of even width and of hemp fibres is obtained by observation with Differential Interference Contrast microscope (D.I.C.), and the combination of P.O.L. and D.I.C microscopes illustrates the papermaking fibres in details, but various conditions and different origins of the fibres make identification complicated. The chemical and mechanical preparation process destroys botanical characteristics of the fibres, especially in recycled material having a repeated preparation process. A few elements are, however, unchanged such as the lumen, the original shape of preserved fibre ends and the general character of the surface and morphology of the fibres.

Distinctive features of the fibre material

Some plants are more sensible to the preparation process, and this helps to distinguish the more fragile hemp fibres from flax fibres. Because of the good condition of the flax and hemp fibres with less fibrillation and frayed fibre ends than normally found in Asiatic and European paper the microscopic analysis of Arabian paper has resulted in valuable knowledge about the way these fibres react in paper production. Flax and hemp fibres have many features in common, but a few leading elements help to distinguish between the two fibre materials.

Distinctive features of hemp fibres in paper are (i) slightly irregular lumen, (ii) splits and swellings indicate high sensibility to the preparation process, (iii) different looking fibre ends in one and the same fibre, ramified fibre ends occur most frequent, (iv) presence of star shaped cluster crystals and prismatic crystals.

Distinctive features of flax fibres in paper are (i) very narrow, even lumen, (ii) vertical striations less prominent than in hemp, (iii) tapering pointed and tapering rounded fibre ends, (iv) lack of crystals.

New development of paper production

In Europe water-driven fulling mills are normally used as after-treatment of woollen textiles. The innovative papermakers in Fabriano, introduce, however, during the end of the 13th and start of the 14th century the local fulling mills as new and more efficient tools for the mechanical treatment of the retted rags compared to the Arabian pounding by hand [5]. At the same time the knowledge of the local metal work inspires the papermakers in Fabriano to a new construction of the papermaker's most important tool – the mould with a fixed, rigid screen of metal wire of horizontal laid lines, crossed by vertical chain lines and with a filigree of metal thread – a watermark – sewn on top of the metal wire. This new Italian mould replaces the Arabian mould with a loose-lying, flexible screen of reeds [6].

The European watermark serves as a logo for the paper mill and quality of the paper in a similar way as the logo stamped on silver ware, led seals on textiles or wax seals on documents serve as a guarantee of genuineness. During the sheet formation an impression of the woven structure of the metal wire is left in the paper with the vertical chain lines and horizontal laid lines and watermarks, visible only when the sheet of paper is held against light. To increase the production a pair of identical moulds and a common deckle frame is used in the sheet formation.

Tycho Brahe's paper and paper mill

Recycled flax and hemp fibres are similar to the Arabian and the original Chinese rag paper used as fibre materials for the European rag paper production as illustrated by the D.I.C. observation of a watermarked paper of German provenance from the Royal Library in Copenhagen. Registration of a collection of 16th century watermarks observed in Danish manuscripts illustrates that import of European paper is highly needed, because very few Danish paper mills are in function at this time. Only one watermark in the centre of the top line is of Danish origin in this registration.

Fig.2 Watermarks from European writing paper and from Tycho Brahe's writing paper

It is the watermark that the Danish astronomer and nobleman Tycho Brahe used for his personal writing paper. Without a paper mill on the Island of Ven in the Sound between Denmark and Sweden Tycho Brahe is completely dependent on access to the imported European paper, and he needs paper for his astronomic observation and publication of his research. The island is flat without any forest and thus ideal for astronomical observation. Tycho Brahe compensates, however, for the absence of a natural watercourse by means of a string of artificial ponds leading the water to the mill, situated further down at the beach. Gviljelmo Blaev's map from 1590's of the island illustrates the artificial lakes established as the necessary supply of water for the paper mill. On this map Blaev has with a drawing preserved the knowledge about the position and unusual construction of Brahe's paper mill with the overshot wheel, driven by the gravitation of the falling water from the mill pond and its position at the beach of the island.

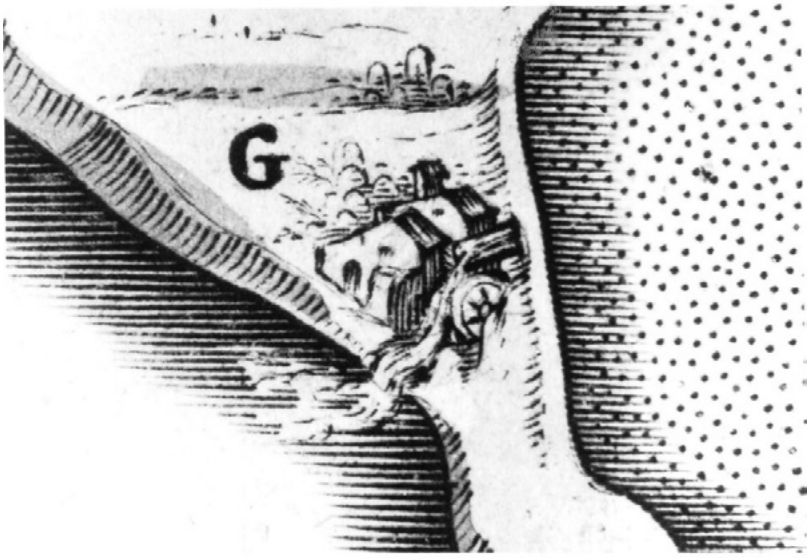

Fig.3 Blaev's drawing on the map of Brahe's paper mill

The mill only functions, until Brahe in 1597 leaves Denmark for good and settles in Prague, where he dies 1601.

Sheets of paper from Brahe's paper mill on Ven have been located through studies and registration of his watermarked manuscripts at the Royal Danish Library in Copenhagen. The macroscopic and microscopic observation of samples of the paper illustrate and document that Brahe's paper is of similar high quality as the best imported 16th century European writing paper. S.E.M. observation of the writing paper surface with lime particles on the fibres illustrate that lime has been added, similar to European writing paper production during the final stamping process in Brahe's paper mill. Addition of alum to the gelatine sizing delays the putrefaction of the gelatine and makes the sizing material less water-soluble than starch sizing and thus more resistant to humidity. As the only paper mill in the region there is obviously no problems of access to fine qualities of clean rags for Brahe's paper mill on Ven. Smooth and well preserved flax fibres and more fibrillated and thicker hemp fibres are characteristic for Brahe's fine writing paper as well as for European writing paper of similar qualities.

Brahe's printing paper

Registration of watermarks and paper qualities of Brahe's manuscripts and letters at the Royal Danish Library tell us, that not only writing paper, but also printing paper for publication of the results of his research is produced in the paper mill on the island of Ven from 1592-1597 . Studies of his printing paper and the impression of the more open wire structure with only 18-22 laid lines per 3 cm instead of 30-32 laid lines per 3 cm as in his writing paper illustrates that he has adapted the metal wire of his mould and his printing paper quality to Johann Gutenberg's 15th century printing process with movable laterally reversed led characters and a thick and viscous printing ink of a mixture of linseed oil varnish and soot. Gutenberg's invention of the printing press resulted in demand for a more hygroscopic paper quality with a weak sizing or no sizing at all than the one used for writing with pen and ink. Hemp fibres of various lengths dominate the fibre material of the samples collected from Brahe's printing paper with a prominent degree of fibrillation and irregular and wider lumen than the narrow and even lumen of linen fibres. The watermarks of the printing paper are difficult to register because of their position at the centre of the book, where the sheets of papers are stitched to the spine of the book.

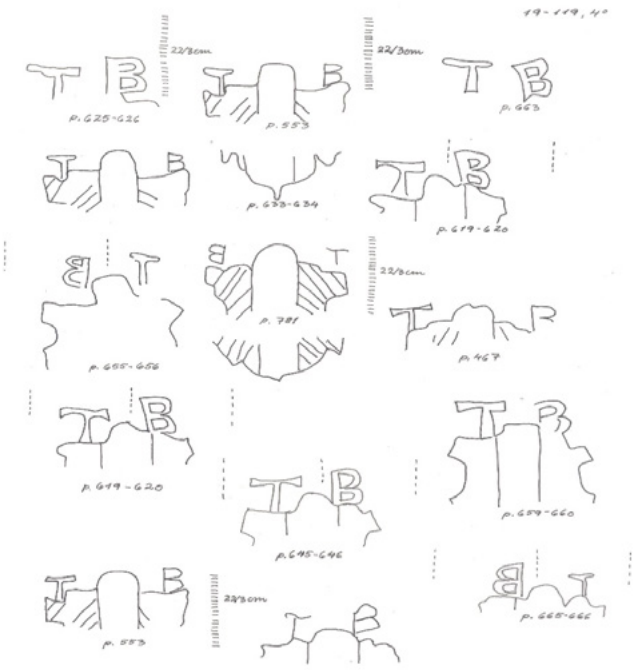

Fig.4 Watermarks from Brahe's printing paper

17th century paper and watermarks

After a period of nearly 30 years without Danish paper production paper mills are finally established on the order of King Christian IV and the new Danish Bible from 1647 is printed on a mixture of Danish paper from new papers mills and imported European paper. The watermarks are now bigger than in the 16th century, and Christian IV's crowned monogram documents that the papermaker has received

the Royal privilege for paper production from the king. The crowned watermark with the city arms and initials of the papermaker registered in the sheets of paper in the Danish Bible indicates the provenance of the paper mill, established in 1637 in Scania. D.I.C. observation of the fibre material illustrates that the condition of the mixture of recycled thin and even flax fibres and thicker hemp fibres with the characteristic frayed fibre ends with a limited fibrillation points at a moderate stamping process of the Danish printing paper from the Scania paper mill. At the end of the 17th century a sample of French drawing paper at the National Museum of Denmark with the Foolscape watermark tell about the import of this high quality paper, consisting according to the D.I.C. observation of a mixture of linen fibres with narrow lumen and even width and longitudinal striated hemp fibres with frayed fibre ends [7].

Illustration and description of the art of papermaking

In spirit of Enlightenment in the following century the renowned French Academy of Sciences in Paris asks the astronomer Joseph-Jérôme-Lefrançais de Lalande to collect information from the paper mills and papermakers for the first thorough description of European papermaking craft. His book 'L'Art de faire le papier' is published 1761 with a number of detailed prints from the end of the 17th century (1698), illustrating the various processes and tools [8].

The collected rags of worn-out textiles are first of all sorted into three different grades according to whiteness and strength in fine, medium and coarse and afterwards cut into small pieces, where buttons and thick seams are removed and finally rinsed in running water in the basement. The sorted rag material is weakened here during a controlled retting process, until the right degree of mouldering is obtained. This is very similar and most likely inspired by the method used in isolating the bast fibres from flax and hemp plants through retting and mechanical treatment before spinning and weaving.

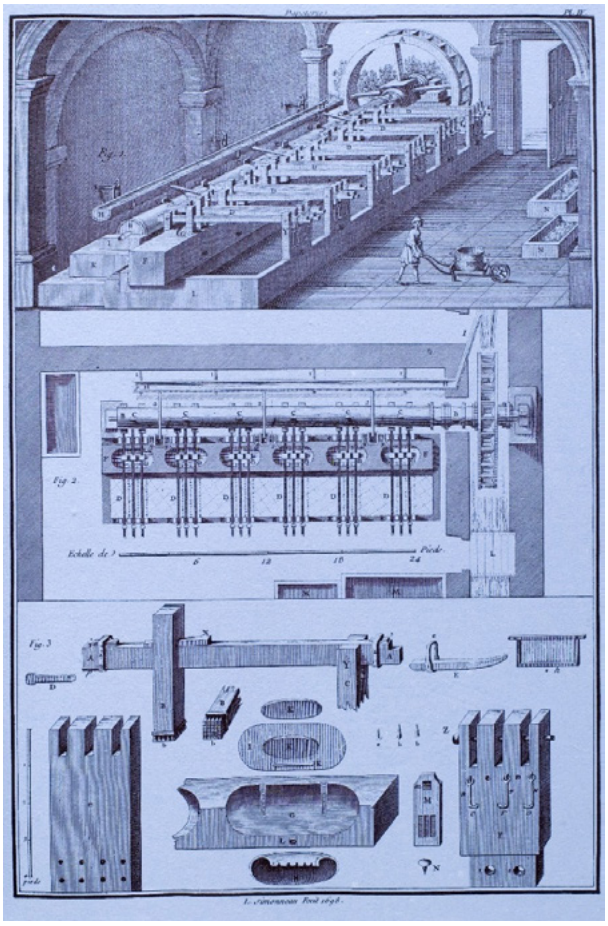

Fig.5 de Lalande: stamping mill, Plate IV, 1698.

The moulded rags are during the mechanical grinding by three hammers in the vat holes now completely dissolved with addition of water and rinsed for water-soluble dirt. Water is added to the vat holes except for the last one, where the total disintegration of the woven structure into individual recycled linen and hemp fibres is obtained by addition of lime particles to the dry stamping process. S.E.M. observation of the surface of 16th century Danish printing paper illustrates the open structure with presence of lime particles on the surface of the randomly distributed fibres. These lime particles function as an internal buffer of the fibre material of importance for the durability of the paper.

The illustration in de Lalande's book 'L'Art de faire le papier' gives step by step from right to left information about the European sheet formation technique, invented and developed in the 13th – 14th century in Fabriano. To increase the paper production, two papermakers – the vat-man and the coucher work together in the sheet formation process. With his mould the vat-man scoops pulp of fibres and water of a gentle temperature from the vat. The watermark is created as an impression/embossment of the wire structure in the new web of fibre during drainage of water, when the mould is lifted by the vat-man that removes the loose deckle, before he slides the first mould with the sheet of paper to the drainage plate. Here the coucher takes the mould with the new sheet of paper and couches it out onto a woollen felt on top of the post or pile of sheets and covers the new sheet with another felt. Now he is ready to receive the next sheet of paper that the vat-man has scooped with the second mould. After the sheet

formation follows the pressing of the post of papers and felts for removal of superfluous water. Two other papermakers – the layers – separate the pressed post of papers and felts in two piles, before the second pressing of the pile of papers without felts takes place in the vat-press. The still humid sheets of paper are carried to the drying loft, where the sheets are hung on strings covered by horsehair for a free drying process by air. The speed of drying is controlled by the opening degrees of the window shutters.

The Italian papermakers replace in the 14th century the Arabian starch-sizing with gelatine sizing of the paper as illustrated on the 1698 prints in de Lalande's book. The gelatine is prepared by cooking remnants of skin and hides from the local leather production in a vat. From here the size is filtered into another vat through a strainer for removal of impurities, before the sizer-man dips the sheets of paper into the sizing vat, where the gelatine is kept at a gentle temperature. Now follows the removal of superfluous gelatine size from the post of sized sheets in the press, before the gelatine-sized sheets of paper are dried for the second time in the drying loft.

The Hollander beater

Increased demands for more paper after Johann Gutenberg's invention in the 15th century of printing results in the 17th century in the invention of the pure mechanical Hollander beater that revolutionizes the whole preparation process of the rag material and replaces the time-consuming retting and stamping process. A combination of the technology of the knife stamper and edge runner hitherto used in the wind paper mills in the Netherlands results in the development of the new engine with the driving gear at its top. The pieces of rags are now rinsed and dissolved in one day into individual fibres, and the Hollander beater is soon applied to other European and British paper mills.

For disintegration of the textiles in the Hollander beater addition of lime particles in the final stamping process is no longer needed, but the importance of this buffer of lime particles within the fibres for the permanence and durability of the European paper is not considered, and after the introduction of the Hollander beater lime is no longer added at the paper mills. Because of the lack of white rags of good quality for writing and printing paper bluing of the paper by addition of blue pigments and fibres is needed to obtain a less yellowish shade. Optical registration of fibre widths and lengths on transparent paper from drawings from the start of the 19th century on Dutch paper reveals the presence of blue particles of smalt added for obtaining a white paper.

Bank note paper and rosin/alum sizing

Danish paper for printing of bank notes at the end of the 18th and beginning of the 19th century has been secured against forgery in several ways through a combination of the printed text, stamps embossed in the paper, handwritten signatures and very complicated watermarks.The transparent photo illustrates the construction of the metal wire with diagonal chain lines and numerous watermarks of characters indicating

the value of the banknote. The mould is destroyed by the paper maker after the number of sheets ordered has been delivered to the bank. The S.E.M. EDX analysis of the surface of a Danish banknote paper from 1798 documents that the papermaker has added smalt as a bluing agent to his paper for obtaining a white paper quality for the bank notes ordered. Well preserved recycled hemp and flax fibres are chosen by the papermaker for obtaining the good quality needed for the bank notes.

The lack of good quality rag material is clearly indicated by the condition and dominance of the hemp fibres from a Swedish drawing paper from the middle of the 19th century. Addition of rosin/alum sizing to the pulp is a new and less time-consuming process than sizing with gelatine as an after treatment of the sheets of paper, but the permanence and durability and strength of the paper are reduced because of the increased acidity of the paper.

Wiesner's comparative analysis of Arabian and European paper

Julius Wiesner's first scientific analysis of Arabic paper, European paper and of Central Asian paper results in real data about the origin of the fibre materials and technology used of importance for the history of paper and the provenance of paper with or without watermarks. Drawing with detailed microscopic observation of the ancient fibre materials is a new method of documenting and sharing the information found. Not only the fibre identification of the Arabic codices has Wiesner's interest, but also the starch sizing of the paper that he registers with spot tests of iodine. His chronological analysis of the collections of Oriental, Egyptian and European archival materials is concentrated on the origin of the fibre materials and sizing from the 9th century until the 19th century. Here the data about the replacement of starch sizing by gelatine sizing in the earliest production of Italian paper qualities and fibre materials used can be considered as a kind of birth certificate of the European paper production [9].

Filigranology

A new scientific field within the history of European paper starts in Italy simultaneously with Wiesner's analysis of Arabic and European paper in Vienna at the end of the 19th century. Watermarks are studied by the brothers Aurelio and Augusto Zonghi in the local archives of Fabriano, and collected, registered and published 1881 and 1884 in albums [10]. Their watermarks registered by tracings on transparent paper are gathered according to motives and time of origin as illustrated by my copy of the winged two-legged dragon, used from 1372-1412 [11].

The publication of the Zonghi albums in Fabriano inspires the Swiss paper dealer Charles-Moïse Briquet to a similar registration of watermarks and collection of information from the still existing Swiss paper mills. He follows the Zonghi method of registration of the watermarks according to the motive as the many mermaids in the copy of his tracings illustrate and publishes in 1907 "Les Filigranes. Dictionaire historique des marques du papier dès leur apparition vers jusqu'en 1600" in four volumes.

Conclusion

As illustrated in the print from de Lalande's publication 'L'Art de faire le papier', the examination of the sheet of paper, held against light is important for the discovery of eventual errors, before the paper is ready for distribution. Paper historians, paper conservators and filigranologists also examine paper in this way in their study of the paper quality, the technology, the impression of the metal wire structure with chain lines, laid lines, shadow lines and watermarks.

Watermarks are, however, not to be found in numerous sheets of paper in European manuscripts, books, prints and drawings because of the cuttings in various formats of the paper. These samples of paper naturally have to be studied as well, because of the valuable paper historical information about the technology and fibre materials present here.

I have experienced in my studies of Oriental and of European paper without watermarks of filigree that information about the technology and fibre materials and eventual provenance can be discovered through the technological development of Oriental and European paper production. By studying the very paper with and without watermarks I will follow in the footsteps of these women at the French paper mill and look at paper.

Notes/ references

[1] Hill, R. L. '*Early Italian Papermaking, a crucial technical revolution*'
IPH Yearbook 1992, Volume 9, p. 37-46

Tschudin, P.F. *'Paper comes to Italy'*
IPH Yearbook 1998, Vol. 12, p.60-66.

[2] Dąbrowski, J. *'The genuinely European technique of making paper by hand developed in Fabriano: An interpretation through the mirror of paper technology'*
The Use of Techniques and work by papermakers from Fabriano in Italy and Europe, Congress Book of European Paper Days. 2007, p. 415-443.

[3] Wiesner, J. '*Die Faijûmer und Uschmûneiner Papiere*'
Karabacek, J. Das Arabische Papier, Mittheilungen aus der Sammlung der Papyrus Erzherzog Rainer II-III, Wien 1887, p. 179-240

[4] Rischel, A-G. *'Bonds between Chinese and European paper technology – adaptation and innovation'*
Tradition and Innovation proceedings of the 6th IDP conservation conference, Beijing 2005, p. 26-36.

[5] Hills, R. L. *'Papermaking stampers: a study in technological diffusion'*

IPH Yearbook 1984, Volume 5, p.67-88.

[6] Tschudin, P.F. *'The Mould: Its Function, History and Importance in Historiography'* The Mould. Paper-and Mould-Makers in the History of Western Paper, 2016, p. 118-134

[7] Rischel, A-G. '*Adaptation and innovation in technology and quality – A study of 250 years of Danish and European rag paper'*
IPH Yearbook, Vol. 15, 2004, p. 105-115.

[8] Lalande, J.J.J. Lefrançais de. *'L'art de faire le papier'*
Description des arts et metiers. IV Paris. Academie Royale des Sciences, 1761

[9] Wiesner, J. '*Untersuchung orientalischer und europäischer Papiere aus dem IX bis XIX Jahrhundert*'
Karabacek, J.: Das Arabische Papier, Mittheilungen aus der Sammlung der Papyrus Erzherzog Rainer II-III. Wien, 1887, Fünftes Capitel, p. 241-260.

[10] Castagnari, G. *'News on the acquisition of the sample-collection „Raccolta Augusti Zonghi".*
IPH Paper History, Volume 20, Year 2016, Issue 2, p. 19

[11] Haidinger, A., Peck-Kubaczek, C. *'Aurelio Zonghi'*
Bull's Head and Mermaid, The Bernstein Project, Booklet of the Exhibition, p. 78-79