More than meets the eye: Fibre and Paper Analysis of the Chinese Manuscripts from the Silk Roads

Agnieszka Helman-Ważyń

Centre for the Study of Manuscript Cultures, University of Hamburg, Germany

Abstract This study contributes to the history of paper in Central Asia during the first millennium C.E. and aims to create a typology of paper based on a systematic study of Chinese manuscript collections found along the Silk Roads. The further aspect of this study aims to improve our knowledge of archaeometric research considered with the revision and test of scientific methodology which can then be used for historical and philological scholarship. By using fibre analysis and the technological study of paper combined with codicological and textual information, research has aimed to explore the possibilities for dating these materials, and fingerprinting their places of origin. The fact that many of Chinese manuscripts being studied (which are the oldest preserved and dated artefacts from Central Asia) are fixed in time by dates mentioned in colophons makes them valuable and reliable references for building a typology of paper and for comparative study of any yet to be discovered papers from that region.

A sample of studied manuscripts comprises a total of 182 Chinese manuscripts selected from the Dunhuang Collection in the British Library in London, the Bibliothèque Nationale de France in Paris (BnF), the Institute of Oriental Manuscripts in St. Petersburg, and the Turfan collection in the Berlin Brandenburg Academy of Sciences (BBAW) and the Berlin State Library (StaBi).

Received 18 December 2015; accepted 7 June 2016

Statements of significance

Manuscripts and paper objects are usually only rarely encountered at archaeological sites largely because of the impermanent nature of the organic material, but also because of difficulties in interpreting the results of material analyses in a wider context. The core problem facing paper analyses in objects of unknown origin is that we lack chronological references for material usage in particular regions. Thus my typology of paper, based on the oldest preserved manuscripts from the first millennium in Central Asia, will lay the groundwork for further physico-chemical examination which is a means to gain further data about production, provenance, use, and re-use of manuscripts. Paper analysis helps to identify provenance and reveals links between groups of objects with the same distinguishable features. At another level this study of provenance and authenticity of materials stands as a highly practical source of information for future forensic investigations aiming at attribution and justification if artwork is a copy or forgery.

Introduction

This study discusses the possibilities and limitations of fibre analysis of the Chinese manuscripts from the Silk Roads. Within the Deutsche Forschungsgemeinschaft (DFG)-funded project at the University of Hamburg titled History and typology of paper in Central Asia during the first millennium AD: Analysis of Chinese paper manuscripts, I have created a preliminary typology of paper based on systematic studies of collections found in Dunhuang and Turfan. The examined manuscripts contain the earliest surviving examples of literacy, artistic expression, scribal practice and recorded materials. Despite their importance, their material components have not yet been studied.

The core problem in the case of paper analyses in objects of unknown origin is that we are lacking chronological references for the materials used in particular regions that might enable us to interpret the results of material analyses in a broader context. Physico-chemical examination is worthy to try to gain more data about production, provenance, use, and re-use of manuscripts. Furthermore, the measurements should be able to show that two or more fragments belong to one and the same manuscript or not, and further which manuscripts belong to the same group of materials and thus can be defined as ‘a type’. This type then could eventually be linked to manuscript locality and sometimes also to chronology.

*Corresponding author, email: agnieszka.helman-ważyń@uni-hamburg.de

© 2016 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

10.1080/20548923.2016.1209055

STAR201620548923.2016.1209055
More generally, the questions can be raised if the different religious and ethnic communities and their scribes along the Silk Roads in Central Asia were using the same suppliers for paper and other materials for manuscript production. A further aspect of this study aims to improve our knowledge of archeometric research for manuscripts and is focused on revision and testing of scientific methodologies which can then be used for philological scholarship.

Paper analysis helps to identify provenance and reveals links between groups of objects with the same distinguishable features. By identifying fibre composition and studying variations in production methods, raw materials, and tools’ traces sealed in paper, it is to some extent possible to determine time and place of production and understand the technologies involved. However, to achieve greater precision of such estimations, it is necessary to collect and study more reference materials which will contribute to our overall understanding of what type of paper was used, and where.

Thus my results contribute to the reconstruction of the early history of paper in Central Asia. This subject has been studied by many scholars, but most of what is already published and concerned with early paper history is based on only a few written sources repeatedly used as references (Karabacek 1887 and 2001; Laufer 1931; Hunter 1932 and 1978; Carter 1955; Pan 1979, 1981; Bloom 2001). This general lack of records is a main reason for the blank spaces in the early history of paper. Despite the long-lasting tradition for making paper in China, it is difficult to reconstruct the history of papermaking in particular regions of Central Asia, and no systematic study has yet been made.

The combined photographic and descriptive documentation produced from each of these samples will be highly useful for any future investigations that might aim toward attribution and justification if artwork is a copy or forgery. The techniques and equipment are the same whether one is engaged in the forensic examination of the object or conducting an investigation to aid art historians or paper conservators. However, the burden of proof required by these various disciplines is very different.

Features of paper from Central Asia in the first millennium come from the actual method of making paper at that time (Helman-Waży 2014). For a better understanding of technical terms, a description of the papermaking process is given here before the analytical breakdown.

Before starting the preparation of fibre pulp, the collected raw materials (rags, phloem of trees or the other parts of plants) were cleaned and soaked for several hours in order to separate the fibres from the surrounding tissues. The soaked fibres swell and their structure loosens up, which results in a higher degree of fibre separation. For a better result, the material prepared in this way was usually boiled for a couple of hours in water filtered through ashes from a fire. Boiling removes the interconnections between fibre bundles. Unless the raw material is boiled well, it is difficult to soften and the resulting pulp will not be evenly distributed when poured on the papermaking mould during the next stage of the process. Uneven fibre distribution observed in the finished paper is often caused by inadequate preparation during this stage of the process.

Most often paper pulp is prepared by beating the materials upon a stone with a wooden mallet. This pulp is then mixed with water and poured on a sheet mould in measured quantities. The papermaker moves the frame in the water until the pulp entirely and equally covers the surface of the mould; he/she then tilts the frame until the water drains off. There are two methods of making paper: the ‘floating’ type, which is when the papermaking mould is floating on the water surface and paper pulp is poured on the screen directly within the frame of the mould; or the ‘dipping’ type, in which case the pulp is mixed with water in a larger tank and the papermaking mould is

**Figure 1** Paper pulp being poured on the ‘floating’ type of mould placed on the water surface in the wooden tank. The papermaker stirs up a quantity of the pulp with his hands, then moves the frame in the water until the pulp entirely and equally covers the surface of the mould; she/he then tilts the frame until the water drains off. Kathmandu, Nepal (2016).

**Figure 2** Mr. Ma Songsheng from Beizhang Village (South of Xi’an) making paper on a dipping mould equipped with a bamboo screen (April 21, 2013).
in this case dipped into the tank, and the pulp is scooped into the mould (see Figures 1 and 2). Usually the dipping method resulted in paper sheets that were thinner and more even in thickness.

When using the floating moulds, the newly made sheets of paper needed to be left undisturbed until the sheets were dry. This method not only prolonged the already time-consuming papermaking process but also limited the amount of paper produced because the number of sheets of paper produced is determined by how many moulds the papermaker owns. This limitation encouraged the popularity of the alternative ‘dipping’ method because a type of mould with movable sieve is used. The mould with movable sieve allows faster paper production because it is possible to remove a wet sheet of paper from the sieve just after its shaping. This means that papermakers do not need to wait until the paper has dried before re-using the mould to produce the next sheet. This type of mould with its more sophisticated construction is thought to have developed later than the ‘floating mould’ with fixed sieve.

Depending on the papermaker’s skills and habits we can then observe in the paper structure the direction of fibres and how evenly they are spread within the sheet. The process of shaping the paper sheet using this method requires meticulous adherence to technicalities. The thickness of the paper could vary if the papermaking mould is turned in one direction only while stirring the water. The size of the paper

Figure 3 Various types of papermaking moulds: a) European mould with wired metal sieve; b) ‘Dipping’ type of mould with movable bamboo sieve commonly used in China and East Asia; c) ‘Floating’ type of mould with textile sieve fixed on wooden frame (also called “woven type”); d) Various sizes of woven type of moulds.
sheet is still determined by the size of paper frame/mould.

The main difference between the two types of mould is in their construction. The floating mould comprises a wooden frame with a woven textile attached to it. In the case of the dipping mould, on the other hand, a movable sieve made from bamboo, reed or another kind of grass is attached to the wooden frame (Figure 3).

Independent of both techniques for forming sheets and the type of raw materials used, any paper-making sieve makes an impression that is specific to the construction of the mould and sieve. This print is unaffected by aging processes and can serve as one of the primary features for identification and typology of paper in manuscripts. The print of a textile sieve made of cotton, hemp, or flax differs clearly from that of a moveable sieve from a dipping mould made of bamboo, reed, or other grasses. Patterns of chain and laid lines in the paper structure allow us to distinguish a handmade woven paper and handmade laid paper characterized by particular numbers of laid lines in 3 cm. Whenever possible, the measurement of the interval between two chain lines is determined (Figure 4). However, this information alone is not necessarily definitive and cannot be used for the identification of paper origin alone, nor for dating. Thus, the samples described here will be interpreted only together with other features of paper, such as fibre composition, fibre distribution, and other formal features of manuscripts.

Goals of the research

By using the systematic technological and microscopic study of paper combined with codicological and textual information, my research has aimed to explore the possibilities of creating typology and dating these materials, finding their places of origin, and recovering the histories of their regional production and usage. Overlapping typologies of paper were used to classify a sample of manuscripts into coherent groups, and then relate them to different geographical regions and time periods.

Material

The core group of manuscripts sampled for fibre analysis was selected from the Dunhuang Stein Collection in the British Library in London and from the Turfan collection in the Berlin Brandenburg Academy of Sciences (BBAW) and Berlin State Library (StaBi). This group comprised 130 Chinese manuscripts, including 110 originating from Dunhuang and 20 from Turfan. The date when the text was copied has been preserved in the colophons of 47 manuscripts among my selection (Giles 1957). The dated manuscripts have been assigned to a time between the fifth and tenth centuries. The oldest manuscript, S.797, whose text describes the Buddhist rules for monks, Pratimoksa sūtra, is dated to 406 CE (Figure 5). The colophon of this manuscript mentions a place located in the south of Dunhuang (Giles 1935a, 810). Among the earliest dated scrolls in my sample are three more dated to the fifth century, 10 dated to the sixth century, and 14 dated to the seventh century. They almost all include Buddhist texts, with only one Taoist text found among the manuscripts of the seventh century. The Buddhist works form more than three-quarters of the whole collection and include all the principal sutras, Vinaya, and Abhidharma texts (for the history and content of the British Library collection see: Whitfield 2002, 2007; van Schaik and Galambos 2012). Uncanonical Buddhist, Taoist, Manichaean, secular, and other miscellaneous works comprise the minority of the collection. In fact, there are many texts which repeat in different scrolls. The idea of producing of sacred texts, prayers, and images has always
been central to Buddhist practice as an act of gaining merit. The most recent manuscript, 5.4760, is dated to 981 CE and is composed of rag paper and contains a secular text. It is of course possible that the undated manuscripts may have been composed earlier than 406 CE or later than 981 CE.

The famous copy of the Diamond Sutra printed in 868 CE has also been selected for this paper study as it is one of very few early woodblock prints among the Dunhuang collection. This paper scroll with a finely carved frontispiece is presently dismounted into separate panels and preserved flat in a box after thorough conservation recently performed in the British Library by Mark Barnard (Wood and Barnard 2010).

To achieve a greater variety of paper types and extend my comparanda, I also selected 22 Central Asian manuscripts written in Chinese from the Pelliot collection preserved in the Bibliothèque Nationale de France in Paris and another 30 from the same category from the Oldenburg collection preserved in the Institute of Oriental Manuscripts in St. Petersburg. This extended my study group to 182 total manuscripts. Examination of these additional manuscripts was conducted by measuring technical features by eye.

All together this group of 182 manuscripts written in Chinese has served as experimental material and as a starting point for creating a typology of paper. Here the selected features of paper and both format and content of manuscripts recorded is described within a cultural group of manuscripts written in Chinese. Both script and language of the text are usually the first obvious features to consider when approaching a manuscript. However, it needs to be noted that a Chinese script does not necessarily imply that the scribes were Chinese. This explains why in this study I start to examine manuscripts of the same script/language groups, but then prioritize by the particular types of paper, independent of other features.

Methods

My work from a practical point of view was divided into stages. First, the selected manuscripts were studied with simple codicological methods in the libraries and institutions where they are housed. This was done during consecutive week or two-week trips during which I organized mobile laboratory to describe technological and visual features of paper and sample manuscripts for fibre analysis.

Measurements by eye

Technological features of paper manuscripts were examined on a light box. First, documentation of paper translucency was conducted by placing a scroll or folio on the light box. Then fibre analysis test location(s) were documented. At this stage, all possible measurements by eye were conducted as listed below.

- a. Visual features of paper: presence or absence of yellow dye; other features derived from methods of preparation of the leaves before writing, if visible.
- b. Number of leaf layers, if possible to read.
- c. Technological features of paper: Manuscripts were checked on a light box for papermaking sieve print type (woven or laid) attached to the mould, and measurements of laid lines in 3 cm and chain line intervals, if visible, were recorded. The measurement of chain line intervals is given only for distances possible to measure (where chain lines are clearly visible). These intervals often vary within one paper sheet, and in this case, the sequences of span values are given. Photo documentation of paper structure against light was performed.
- d. If visible, the fibre distribution within a sheet (whether the fibres were poured into the floating mould and distributed by hand or scooped by the mould from a vat, and how quickly the drainage of the pulp took place).
- e. Thickness was measured in several places.
- f. Sampling for fibre identification (usually one sample per scroll; otherwise if more than one type of paper in the scroll/document was noticed during primary examination by eye, more samples were taken from different paper types).

Fibre identification by microscopy

Then microscopic study was conducted at the Manuscript Laboratory of the Centre for the Study of Manuscript Cultures (SFB 950) at the University of Hamburg on the samples collected in situ (see above). The aim of the procedure was fibre identification in paper using an Olympus BX51 Transmitted-Reflected light microscope with BF/DF/DIC/PL with an Olympus UC30 camera attached for photographic documentation. Olympus Stream Software was used for image analysis during identification. A varying magnification from 70x up to 600x with both plain and polarized light was applied. Then date and place of analysis were recorded.

Fibre analysis is usually performed as documentation before conservation treatment, in order to choose the best method for conservation (Collings 2016).
and Milner 1978, 1979). This is standard protocol for a particular case study, but not necessarily for a larger group of objects. Here the goal was to collect the evidence from a larger collection with a known historical background. Other aims were to learn about the relationship between raw materials used and properties of the resultant paper; to deduce origins of paper by comparing fibre identification results with the local occurrence of the same plant; and to know more about fibrous materials used for papermaking in the past to trace the history of papermaking.

Results and discussion

Fibre analyses

Considering the type of raw material within my sample of 130 Chinese manuscripts tested for fibre composition, two main types of rag and bark paper and four sub-types of rag paper have been distinguished. However, the majority of manuscripts (88) were composed on rag paper. There were 75 samples out of 110 Dunhuang manuscripts written in Chinese identified as rag paper and 13 samples out of 20 from the Turfan collection. After rag paper, the second largest group significantly represented among the Turfan and Dunhuang manuscripts contains bark (phloem) paper (42) composed of woody plant phloem fibers, such as Broussonetia sp. (paper mulberry) or Morus sp. (mulberry), derived from living plants. These are considered to be the best materials for creating high quality paper.

Rag paper

These findings suggest that rag paper was probably broadly produced in the first millennium in Central Asia and was the common material for making paper at that time. Judging from the availability of resources for papermaking, the Dunhuang and Turfan area could be the obvious place where this type of paper was produced, especially when taking into account the fact that cultivation of papermaking plants required a lot of effort in this desert region, or would be impossible. The only possible plant which could be used for making paper along this part of the Silk Road was mulberry (Morus sp.) cultivated for silk production. However, this was probably not a main raw material used in the region, since the purpose of cultivation of mulberry trees was to breed silk worms and produce silk, which was much more profitable for owners (Figure 6). In addition, papermaking requires the cutting of young branches, up to two years old, which up to a point could stimulate growth of leaves, but could also quickly damage the tree if exploited on a large scale.

On the other hand, despite the fact that rag paper seems to be associated mostly with the northwestern part of China, we cannot exclude that this type of paper, representing the oldest known technology in China, could have been produced elsewhere. Rags and old cloths and robes were accessible almost everywhere. Anyhow, the significant proportion of rag paper found in the Dunhuang and Turfan area confirms the hypothesis of the local availability of rag paper. This is also confirmed by some colophons pointing to the local place of manuscripts’ production.

With regard to fibre components, I identified four distinct groups of rag paper in my sample. These are:

A. Rag paper composed purely of hemp. Within my sample dated to the first millennium CE, only 4 papers (S.2598, S.5529, S.5747, S.6726) were made of pure hemp as compared to 84 made of ramie, some with a hemp addition, which was most typical of the rag paper identified. Hemp plants were known as early as the Neolithic time in China. By the time of the Zhou Dynasty (c. 1046–256 BCE), hemp fabrics were widely produced to provide clothing for labourers, and entered the market as an attractive commodity for merchandise (Cheng 1992, 122). No doubt hemp fibres were used for textile production practically throughout all of China long before paper was produced. Interestingly, hempen cloth did not count as a fabric of great value, and probably this is why such cloths were excavated only in insignificant quantities in imperial tombs. This makes them the perfect material for recycling for paper production. Cheng mentioned that hemp cloths were universally

3The Herzberg stain is frequently used to detect the presence of specific fibers in a paper.
used during the time of the Han Dynasty for making uniforms for low-ranking officers and privates. He testifies to this by pointing to the discovery of a large amount of hempen products unearthed from an ancient beacon tower north of Lop Nur in Central Xinjiang (Cheng 1992, 436).

B. **Rag paper composed of mostly ramie, sometimes with a small addition of hemp.** The majority of samples (84) including the oldest paper mentioned above, dated to 406 CE, is an example of rag paper composed of ramie and hemp fibres (Figure 7). This suggests that both ramie and hemp materials were widely used at that time but that the majority of cloth for making paper was made of ramie, and hemp fabrics were added in smaller quantities. Akira Fujieda and other Japanese scholars pointed to ‘hemp paper’ instead of ‘rag paper’ possibly because of ambiguous terminology (Mitani and Fujieda 2009). Interestingly, Clapperton identified this paper in the 1930s as being made of paper mulberry (Clapperton 1934; Giles 1935a, 811). It is similar to deteriorated rag paper made of short fibres of ramie and hemp in manuscript S.312 also identified by Clapperton as paper mulberry (Clapperton 1934; Giles 1935b, 16). Those differences probably can be attributed to the difference between the type of microscopes available in the beginning of twentieth century and now, and the state of highly deteriorated material. However, Clapperton’s identification of another early manuscript made of rags dated to 506 CE by colophon, S.81, agrees with my current assessment. This paper is characterized by very fine (30–32 in 3 cm) laid lines and a smooth and polished surface, and its colophon points to the Zhulin monastery in Jingzhou (Hubei, South China) as the place where the manuscript was copied.

C. **Rag paper composed of ramie and hemp with the addition of paper mulberry/mulberry (Broussonetia or Morus sp.).** The next group within the category of rag papers (8 samples out of 130) was characterized by a small addition of paper mulberry (Broussonetia sp.). Paper mulberry was not typically used for textile production in China since its fibres are especially long, up to 24 mm, and strong, which is why it is not very suitable for weaving. However, Cheng Weiji mentions paper mulberry fibres as useful for textile production

---

4Manuscripts on paper composed of rag paper with the small addition of paper mulberry: S.6417 dated to 920 CE, 931 CE; S.2775; S.1731; S.1048; S.1523; S.1523; S.4683; S.1600.

---

**Figure 6** Mulberry tree (Morus sp.) currently growing in Toyok.

**Figure 7** Rag paper composed of ramie and hemp fibres in the manuscript S. 797 dated to 406 CE, observed in magnification OM 600x.
together with *Abutilon* sp. fibres, both noted as textile fibres as early as during the Zhou Dynasty (Cheng 1992, 57). Another possible source of paper mulberry fibres added to rag paper is monks’ cloths made of paper. Besides paper mulberry derived from assumed fabrics or paper cloths, fragments of tapa (screens made from pounded bark placed perpendicularly to each other in layers) could have been used together with rags for making this type of paper. This is why it is not very surprising that we can find paper mulberry as a component of rag paper. On the other hand, the presence of paper mulberry fibres in paper might also suggest a shortage of rags in the area and the need for technological innovation in paper production. In such a case, this addition could suggest a later date of this type of paper production. This idea unfortunately cannot be supported by information from colophons, since seven samples made of rag paper with an addition of paper mulberry were taken from undated manuscripts, and only one sample of this type is dated, and that belongs to a scroll with secular text dated to the tenth century.

D. Rag paper composed of ramie and hemp with the addition of singular other fibres such as flax, jute, silk, or cotton. Other additions of fibres, such as flax, jute, silk, wool, or cotton, were found in 15 samples. Interestingly, manuscripts from the Dunhuang collection contained ramie and hemp rag fibres with the addition of jute, flax, and silk, while in Turfan the same rag fibre-composed paper contained an addition of cotton and wool. These additions may possibly be used as a marker for particular areas or time of usage. However, at the moment I do not have enough reference materials to assign location and time to particular fibres. Used silk cloth or jute textile could have been practically everywhere. The Chinese jute (*Abutilon* sp.) fibres are coarser than hemp, ramie, and others, and were used first to make mourning apparel and a minor collarless garment (Cheng 1992, 123). With the passage of time, it was gradually eliminated as a clothing material, and came to be used mostly for cordage. This allows for better understanding regarding why only singular fibres of jute were found in old papers (Figures 8 and 9). I found only single cotton fibres in one Chinese manuscript from Turfan, and nothing in the Dunhuang manuscripts. This addition of singular cotton fibres to rag paper of the manuscripts found in Turfan possibly originates from cotton cloths of Xinjiang known at that time. This type of cotton cloth was well known in the Central Plains of China for its special qualities as early as the later years of the Eastern Han Dynasty (Cheng 1992, 447). At the same time, people were able to weave various types of fabric with different types of animal hairs in Xinjiang. Those fabrics, cloths, or blankets may have been added to other hemp and ramie rags for making paper; and now we see them as singular fibres in some of the papers.

Bark (phloem) paper

In my sample from Dunhuang, 35 manuscripts were composed of *Broussonetia* sp. paper. The oldest example of paper mulberry was found in a yellow-dyed paper of the manuscript S.2660 dated to 504 CE with text of the commentary on the *Śrīmālā-devī-simhanāda sūtra*. The colophon of this manuscript informs us that 11 sheets of paper were used for making it and that the text was jointly revised by monks Baoxian and Xuanji. However, this information does not identify a place of production. Interestingly, manuscripts dated to the eighth century showed a concentration of paper made of paper mulberry or mulberry. The majority of manuscripts executed

---

5Manuscripts on paper composed of rag paper with the small addition of other fibres such as flax, jute, silk, wool or cotton: S.2067, S.6727, S.4528, S.2105, S.529, S.2628, S.1284, S.4683, S.1082, Ch.991, Ch.3201.
on this type of paper were created on a textile sieve or laid patchy. A very good example of this type is the well known early print of the Diamond Sutra P.chin.2.

The other significant group within bark papers regarding type of sieve print indicated a laid regular pattern characterized by 28 to 33 laid lines in 3 cm, which suggests higher technological achievement of papermaking mould construction. These were of exceptionally good quality, with a smooth texture, and often dyed with yellow. This type of paper represented by 42 manuscripts, though primarily composed of *Broussonetia sp.* (paper mulberry), was sometimes also composed of *Morus sp.* (mulberry). However, in most cases, these two species are impossible to distinguish in old paper. This type of bark paper is continuously being found until the eleventh century. Seven papers from Turfan fragments written in Chinese contained paper mulberry fibres. Among the Turfan collection one sample from fragment Ch 565 was composed of paper mulberry, rice straw, and blue sandalwood fibres which are typical components of Chinese xuan paper. This suggests a later date for this manuscript’s creation, most likely later than the first millennium CE.

**Type of paper regarding papermaking sieve print**

**Woven type of paper**

In my sample of Central Asian manuscripts written in Chinese from the British Library, woven paper made with textile sieve—in written sources assumed to represent the oldest and most primitive technology—was found in only 21 out of 110 manuscripts. In the Turfan collection, out of 20 examined samples of paper, five were the woven type. Out of the 22 Chinese manuscripts selected from the Pelliot collection in Bibliothèque Nationale de France only one represented the woven type of paper. Out of the 30 Chinese manuscripts selected from the collection of Institute of Oriental Manuscripts, five are of the woven type of paper.

Furthermore, woven type of paper does not appear at all in papers dated before 692 CE, which is the oldest example of woven paper within the sample described here dated by colophon. Interestingly, those oldest examples of wove paper were made of paper mulberry fibres. Thus, the woven type of paper was represented more within samples of bark paper made of paper mulberry and mulberry; however, only one example of rag paper and a woven type mould dated to 924 CE was identified in the examined manuscripts, and nothing earlier.

Thus, it was not possible to confirm with patterns seen here the assertion of Dard Hunter and many of his followers that a more primitive floating mould with a textile sieve was the earliest and prevalent in the southwestern regions of China and in the Himalayas, whereas in the eastern regions people tended to use a dipping mould with a bamboo sieve (Hunter 1978, 84). At the same time, all of the earliest samples found in Dunhuang show laid paper. Information gathered from colophons was not sufficient to reveal the exact geographical distribution of particular types of paper in such detail, but many of the woven paper samples have likely been produced in south-eastern part of China when considering the distribution of paper mulberry and mulberry trees.

**Laid type of paper**

In the majority of analysed samples, the papers made of rags feature laid lines, showing that they were made on a moveable sieve constructed of bamboo, reed, or grass. Regarding the sieve type and technology of forming a sheet of laid papers, one has to distinguish between regular, irregular, and patchy laid structure of resultant papers. Further, parameters showing the number of laid lines in 3 cm in my sample distinguish papers characterized by possessing 10 to 33 laid lines in 3 cm, and within those four types, independent of whether the laid structure is regular, irregular, or patchy, such as laid paper characterized by approximately 12, 15, 18, and 30 laid lines in 3 cm. However, in the case of a patchy laid structure, laid lines were not always clear enough to count. In general, 60 manuscripts were on thicker paper characterized by 12 to 18 laid lines in 3 cm, often with uneven fibre distribution within a sheet (Figure 10). Out of those 60 manuscripts, 57 were identified as rag paper samples. Twenty manuscripts represented paper characterized by 27–33 laid lines in 3 cm, among which eight samples were made of rag paper and 12 of paper mulberry. It was observed that paper sheets characterized by fewer laid lines in 3 cm usually represented simpler technology and poor quality than those characterized by up to 33 laid lines in 3 cm. For example, the paper with 10 to 18 laid lines in 3 cm, depending on the fragment measured, was observed in scroll S.2925 with Buddhist text dated by its colophon to 455 CE. This was deteriorated rag paper with an irregular and

![Figure 10 Example of laid patchy paper characterized by 12–15 laid lines in 3cm with even distribution of ramie and hemp fibres and rough texture, found in manuscript S.1563 from the British Library Collection.](image-url)
patchy structure (Figure 11). Such a span of laid lines in 3 cm, depending on the fragment of the same paper sheet, suggests the usage of relatively soft material, such as grass, for making the papermaking sieve. These differences occurred based on the type and quality of material used for making the sieve. Depending on what type of supporting material used (bamboo, reed, or grass) and what size (how thin or finely crafted) the resultant ‘laid’ structure of the paper produced is defined as regular or irregular. An irregular print in the paper structure can be interpreted as produced in early times or in areas out of bamboo growing range, where bamboo was not available and a good quality sieve could not be produced.

It is interesting that all of the oldest samples dated by colophons to the fifth century CE were made of ramie and hemp rags on laid patchy paper additionally characterized by irregular laid lines, which suggests usage of a sieve made of reed or grass, not bamboo. This type of paper characterized by the above-described combination of features does not appear in later dated manuscripts, with the exception of two booklets dated by colophon to 905 and 906 CE. All other patchy laid papers are extremely rare, and they differ from my group by raw material or number of laid lines within 3 cm. At this point, more manuscripts dated to the fifth century should be examined to verify these preliminary results. However, there is a clear group with similar characteristics of laid lines in the resultant paper, which includes the majority of the earliest samples. These results also clearly chart the development of the technology of laid/moveable mould making. For example, as mentioned above the earliest examined papers dated to the fifth century CE were patchy and with an irregular laid pattern, then more and more regular laid paper made on a bamboo sieve slowly appeared. An example of laid regular paper characterized by 32–33 laid lines in 3 cm and made of rags with even distribution of ramie and hemp fibres and smooth texture can be found in manuscript S.312, dated by colophon to 673 CE (Figure 12). An example of paper resulting from simpler technology can be found in manuscript S.197, which is written on laid irregular paper, characterized by 12–13 laid lines in 3 cm, made of rags with an uneven distribution of ramie and hemp fibres and rough texture (Figure 13).

In the Turfan collection, out of twenty examined samples of paper, fifteen were the laid type. Within the category of laid paper, five samples from manuscripts Ch 2521, Ch 2836, Ch 991, Ch 422 and Ch 565 were characterized by 27–33 laid lines in 3 cm. All from this group were dyed with yellow and their surface was polished and often highly sized until it boasted a smooth and fine texture. Three of those

---

6S.5534 dated to 905 CE and S.5451 dated to 906 CE.
manuscripts (Ch 2521, Ch 2836, Ch 422) have chain lines clearly visible in large areas in the structure of their paper; however, intervals of those chain lines did not show the same sequence of measurements. In contrast, manuscripts Ch 2757 and Ch 925 were written on rough paper characterized by 9–12 laid lines in 3 cm and made from paper mulberry fibres. This suggests that good quality raw material which usually allows for the highest quality resultant paper was not sufficiently processed, and resulted in a very thick product with uneven fibre distribution. The only rag paper characterized by 12–15 laid lines in 3 cm is Ch 1538. Technologically speaking, this is also low quality paper, but the surface is highly processed with white filler and polished, which improves this paper’s properties and its usability for writing.

Out of the 22 Chinese manuscripts selected from the Pelliot collection in Bibliothèque Nationale de France 21 are laid paper. Ten manuscripts represent papers characterized by 25 to 39 laid lines in 3 cm, and almost all from this group are dyed with yellow with a smooth texture and even fibre distribution, which confirms the high quality of those papers.

Out of the 30 Chinese manuscripts selected from the collection of Institute of Oriental Manuscripts 25 represent laid type of paper. Two manuscripts contain paper characterized by 25 to 30 laid lines in 3 cm. Twelve manuscripts represent laid paper characterized by 18–24 laid lines in 3 cm; seven were on laid paper characterized by 16–17 laid lines in 3 cm; and five were on paper with 11–15 laid lines in 3 cm. A significantly large group of laid papers had a laid, patchy structure.

We can note in connection with the papermaking sieve print pattern that chain lines were sometimes observed on the fragment of the scroll’s panel, whereas none were recorded in the other parts of the same sheet of paper. The presence or absence of the chain lines alone does not always certify that those panels are made of the same or of different paper. The visibility of chain lines within a sheet of resultant paper depends on the construction of the papermaking sieve, and more specifically, the way in which bamboo splints were joined together when the sieve was made. As explained earlier, the marks made by sticks of bamboo are known as ‘laid lines,’ while the less noticeable impressions of the stitches which tied those sticks are termed ‘chain lines,’ as the hair lacing consisted of chain stitching over and under the strips of bamboo. Chain lines observed in fragments of the same panels of scrolls, for example, are caused by the hair stitching having remained in good condition on this side of the sieve mat and being raised enough to make a clear mark in the paper structure. On the other side of the sieve mat, those stitches may be partly broken and flattened, and thus no longer readable as one line. With time and usage of the screen, those hair stitches become softer, and marks are less visible. For example, a reason why chain lines are so clearly visible in European medieval papers is that instead of bamboo and hair stitches, in Europe wire was used to twist around the laid wires to tie them together. ‘Chain wires’ were much harder than ‘chain horse hair stitching’ and this is why chain lines in European papers are always clearly visible as compared to the disappearing chain patterns found in the early papers of Central Asia.

Yellow dye

It appears that the process of dying paper with a yellowish colour was commonly used since the earliest days that paper began to be extensively used for books. Tsien mentioned that yellow dye was first used in the second century (Tsien 1985). Many yellow-dyed papers from Dunhuang were used particularly for Buddhist sutras. Considering the highest quality paper in this group, these could have been produced in inland China for the Chinese court. The presence of yellow dyes was clearly visible in forty manuscripts from my sample from the British Library (Figure 14), and the majority of examined manuscripts from Pelliot collection were dyed yellow, as well as half of the Russian collection examined here. The only tendency I noticed was represented in a group of especially thin laid papers characterized by about 30 laid lines in 3 cm. Interestingly, not all yellow-dyed papers were of the highest quality, as is often assumed in Western literature. Some show a coarse surface with uneven fibre distribution. From my sample I could not observe any specific time period when the paper was dyed with yellow. Further analyses of dyes were not undertaken for the purpose of this study. Based on the literature, besides litharge, red lead, or yellow sulphate of arsenic, which are pigments and not dyes, Chinese paper was soaked in plant extracts that repel insects, and this was the main purpose for its application. This procedure also resulted in a yellowish colour in the paper. Gibbs and Seddon (1998) identified this yellow colour as a natural huangbo dye derived from the Phellodendron

Figure 14  Paper dyed with yellow in Chinese manuscript Pelliot chinois 2413 from BnF. The line distinguishing raw paper and paper dyed with yellow is very clear.
amurense tree. This dye was made by soaking and repeatedly boiling the dried phellodendron bark in water, pounding it, and then straining it through cloth.

Number of layers in the leaf
In nearly my entire sample of 110 manuscripts from the Stein collection in Chinese, single-layered sheets of paper were used for writing; I could identify only eleven manuscripts which contained double-layered paper, including two booklets which included two layers of paper glued together for its covers. Fourteen Chinese manuscripts out of twenty from Turfan were made on a single layer of paper. The other six manuscripts were made on double-layered paper. From the Pelliot collection, only two manuscripts contain double-layered paper. The same pattern is found in the Russian collection. Gluing sheets of paper together is common in covers of booklets, and is also related to the preparation of sheets before writing. Some book formats such as booklets, concertina, or loose leaf pothi are more often layered than scrolls, and since the majority of manuscripts within my sample are scrolls, the lack of layered paper found is not surprising.

Thickness and fibre distribution
Thickness of paper and fibre distribution is strictly related to technological processes and to the preparation of pulp during the papermaking process. Within the British Library Stein collection, slightly more than half of my sample represents uneven fibre distribution. The same approximate balance of papers with even and uneven fibre distribution is represented in the other collections as well. This is a feature which informs us about the quality of paper and the degree of fibre blending. Sometimes in rag papers it is possible to observe fragments of cloths (Figure 15). Bast papers require better skills and heavier processing to loosen and separate all fibres to prepare a pulp. This is why it is sometimes possible to observe fragments of inner bark strips as bundles of fibres. However, irregularities in fibre thickness and fibre distribution most often were caused by the papermaker having lacked the skills necessary to evenly spread pulp during sheet formation (Figure 16). This action is even more difficult to successfully undertake while making large sheets. This effect was a reason for using plants’ extracts or starch solutions added to the water during pulping to help evenly distribute fibres and prevent flocculation.

Conclusions: Typology of manuscripts and early history of paper
The deposit of manuscripts under this study found in Cave 17 in Dunhuang was collected over almost a millennium, which helps to explain why it contained such a variety of materials widely differing in date and place of origin. The Turfan collection which spans even more centuries and comes from various locations around Turfan in general contains only fragments of Chinese manuscripts without much other information. To conclude, I hope that this study has added complexity to the picture of ‘early history of paper and manuscripts in Central Asia,’ by showing that a variety of methods and materials were available to people in Central Asia during the first millennium and later for creating manuscripts that were both more and less elaborate.

The multi-level approach allowed me to sort these dated and undated manuscripts and to distinguish main groups characterized by similar features. To fix these types in time and regional origin those undated are compared to those which have already been dated and identified. Then for better understanding, results were organized according to the main features assigned for the particular levels of typology (Figure 17). These features as described earlier were raw materials identified through fibre analysis and the types of paper were identified based on papermaking sieve print which distinguishes between woven and laid types of paper. Further utilized were auxiliary features such as number of layers in the paper leaf,
presence of yellow dye, and fibre distribution and thickness. Information from colophons was mainly used to help set results in a chronological framework.

The results fall into the following general groups with further subgroups, forming a tree-like typology presenting multi-level data. Considering the type of raw material within my sample of Chinese manuscripts, both rag (with four sub-types) and bark (phloem) paper were distinguished. The majority of manuscripts within all collections under study was composed of rag paper. Rag paper was probably broadly produced in the first millennium in Central Asia and was the common material for making paper at that time. Judging from the availability of resources for papermaking, the Dunhuang and Turfan area could be the obvious place where this type of paper was produced, especially when taking into account the fact that cultivation of papermaking plants required a lot of effort in these desert regions, or would be impossible.

Since studied here Chinese manuscripts of particular groups varied in date and place of origin, they served as important points of reference for the early history of paper in Central Asia. While looking at the types of paper in dated manuscripts we could observe that in my sample, rag papers appear almost alone in manuscripts dated to the fifth and sixth century (with only one example from the sixth century), and then there are only a few manuscripts on rag paper dated to seventh through ninth centuries, while the number of this type increases in the tenth century. According to secondary literature on papermaking around the tenth century, rag paper declined because of the shortage of raw materials and hence its high production cost.

After rag paper, the second largest group significantly represented among the Turfan and Dunhuang manuscripts contains bark (phloem) paper composed of woody plant phloem fibres, such as Broussonetia sp. (paper mulberry) or Morus sp. (mulberry), derived from living plants. These are considered to be the best materials for creating high quality paper.

Within my sample I could observe that bark (phloem) paper made of mulberry or paper mulberry began to balance rag paper at the end of the seventh century, and then to prevail in the eighth. The documents about papermaking after the Song Dynasty (960–1279) mention rag paper occasionally and it is also confirmed by the greater variety of plant components identified in manuscripts dated to later than the first Millennium. The inner white bark of paper mulberry from indigenous trees could have grown wildly or was perhaps cultivated for this purpose.

The woven paper made with textile sieve—in written sources assumed to represent the oldest and most primitive technology—appeared to represent a minority of my sample and, in dated papers, appeared only after 692 CE. The woven type of paper was represented more within samples of bark (phloem) paper made of paper mulberry and mulberry.

At the same time it is interesting that all of the oldest samples dated by colophons to the fifth century CE were made of ramie and hemp rags on laid patchy paper additionally characterized by irregular laid lines, which suggests usage of a sieve made of reed or grass, not bamboo. This type of paper characterized by the above-described combination of features does not appear in later dated manuscripts.

Thus the paper type which I have found most widely associated with early paper produced locally around Dunhuang and Turfan is thicker rag paper characterized by 12 to 18 laid lines in 3 cm, often
with uneven fibre distribution within a sheet. A second type which could have been produced along the eastern part of the Silk Roads is paper characterized by 27–33 laid lines in 3 cm made of paper mulberry and mulberry.

Acknowledgements
This research was funded by the Deutsche Forschungsgemeinschaft (DFG) within the project “History and typology of paper in Central Asia during the first millennium AD: Analysis of Chinese paper manuscripts” (Fr 702/9-1; PI: Michael Friedrich). The author would like to acknowledge the help and support of the director of the International Dunhuang Project (IDP), Susan Whitfield (British Library); Sam van Schaik (curator of the IDP Tibetan Collection, British Library); Cordelia Rogerson and Mark Browne (British Library conservation studios); Desmond Durkin-Meisterernst and Simone-Christiane Raschmann (BBAW); Conservateur en chef Chargée des manuscrits de Dunhuang et des fonds chinois Service oriental Département des Manuscrits de Dunhuang (Bibliothèque nationale de France (BnF)); the director of the Institute of Oriental Manuscripts in St. Petersburg, Irina Popova; and Michael Friedrich, the director of the Centre for the Study of Manuscript Cultures at the University of Hamburg.

ORCID
Agnieszka Helman-Ważny http://orcid.org/0000-0003-1525-767X

References
Bloom, Jonathan M. 2001. Paper before print. The History and Impact of Paper in the Islamic World. New Haven and London: Yale University Press.
Carter, Thomas Francis. 1955. The Invention of Printing in China and its Spread Westward. New York: Ronald Press.
Cheng, Weiji. 1992. History of Textile Technology of Ancient China. New York: Science Press.
Clapperton, Robert H. 1934. Paper: An Historical Account of Its Making By Hand from the Earliest Times Down to the Present Day. Oxford.
Collings, Thomas and Derek Milner. 1978. “The Identification of Oriental Paper-Making Fibres.” Journal of the Institute of Paper Conservation 3, 51–79.
Collings, Thomas and Derek Milner. 1979. “An Examination of Early Chinese Paper.” Restoration and Conservation 15 (2): 39–44.
Mittani, Mazumi and Akira Fujieda. 2009. “New Results of Research on the Chinese Buddhist Texts of the Berlin Turfan Collection. Plan of a new chronological standard of the Chinese Buddhist Manuscripts excavated in Turfan.” http://www.bbaw.de/bbaw/Forschung/Forschungsprojekte/turfanforschung/bilder/berichtMittani (Retrieved April 10th, 2009).
Gibbs, Peter J., and Kenneth R. Seddon. 1998. Berberine and Huangbo: Ancient Colorants and Dyes. The British Library Studies in Conservation Science v. 2. London: The British Library.
Giles, Lionel. 1935a. “Dated Chinese Manuscripts in the Stein Collection.” Bulletin of the School of Oriental Studies, University of London 7.4, 809–836.
Giles, Lionel. 1935b. “Dated Chinese Manuscripts in the Stein Collection.” Bulletin of the School of Oriental Studies, University of London 8.1, 1–26. Published by: Cambridge University Press. Article Stable URL: http://www.jstor.org/stable/608098
Giles, Lionel. 1957. Descriptive Catalogue of the Chinese Manuscripts from Tunhuang in the British Museum. London: The Trustees of the British Museum.
Helman-Ważny, Agnieszka. 2014. Archaeology of Tibetan Books. Leiden: Brill.
Hunter, Dard. 1932. Old Papermaking in China and Japan. Ohio: Mountain House Press.
Hunter, Dard. 1978. Papermaking. The History and Technique of an Ancient Craft. New York: Dover Pub. 4, 129–151.
Karabacek, Joseph von. 1887. “Das Arabische Papier.” Mitteilungen aus der Sammlung der Papyrus Erzherzog Rainer 2/3, Vienna.
Karabacek, Joseph von. 2001. Arab Paper. London: Archetype Publications.
Lauffer, Berthold. 1931. Paper and Printing in Ancient China. Chicago, New York: printed for the Caxton Club.
Pan, Jixing. 1979. Draft on History of Chinese Paper-making Technology. Beijing: Cultural Relics Publishing House.
Pan, Jixing. 1981. On the Origin of Papermaking in the Light of Newest Archeological Discoveries. IPH Information 15 (2): 38–39.
van Schaik, Sam and Imre Galambos. 2012. Manuscripts and Travellers: The Sino-Tibetan Documents of a Tenth-Century Buddhist Pilgrim. Berlin: de Gruyter.
Tsien, Tsuen-Hsuin. 1985. Science and Civilisation in China, v. 5: Chemistry and Chemical Technology; Paper and Printing (Pt. 1). Cambridge: Cambridge University Press.
Whitfield, Susan. (ed.) 2002. Dunhuang Manuscript Forgeries. London: The British Library.
Whitfield, Susan. 2007. ‘The Dunhuang Manuscripts: From Cave to Computer.’ W.L. Idema (ed.). Books in Numbers. Seventy-Fifth Anniversary of the Harvard-Yenching Library. Cambridge, Massachusetts, 113–140.
Wood, Frances, and Mark Barnard. 2010. The Diamond Sutra. The Story of the World’s Earliest Dated Printed Book. London: The British Library.
Woodward, Janet. 2002. “Stains for the Determination of Paper Components and Paper Defects.” Microscopy and Microanalysis 8 (502), 196–197.