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Julius von Wiesner

Über die ältesten bis jetzt aufgefundenen Hadernpapiere. Ein neuer Beitrag zur Geschichte des Papiers. Sitzungsberichte der Kais. Akademie der Wissenschaften in Wien, Philosophisch-Historische Klasse, 168. Band, 5. Abhandlung von J. v. Wiesner, wirkl. Mitgliede der kais. Akademie der Wissenschaften (Vorgelegt in der Sitzung am 10. Mai 1911)

English version of the Austrian publication by Anna-Grethe Rischel

Abstract: This article is an English translation by Anna-Grethe Rischel of Julius von Wiesner's pioneering study of the oldest specimens of rag paper of Central Asian origin conducted soon after the discovery of large collections of manuscripts found in Dunhuang. This work, important for philology, codicology and paper history was fundamental to studies of paper as writing support of old manuscripts carried out at the beginning of the 20th century. The text written in German is little known and is therefore offered here in English.

Key words: Julius von Wiesner, English translation, rag paper, Central Asia, Dunhuang manuscripts, microscopy and paper analysis.

„Z Badań nad Książką i Księgozbiorami Historycznymi" – Udział zagranicznych recenzentów w ocenie publikacji; Stworzenie anglojęzycznej wersji wydawniczej publikacji; Digitalizacja tomów archiwalnych rocznika w celu zapewnienia otwartego dostępu do nich przez Internet oraz wdrożenie i utrzymanie cyfrowej platformy redakcyjnej – zadanie finansowane w ramach umowy nr 653/P-DUN/2019 ze środków Ministra Nauki i Szkolnictwa Wyższego przeznaczonych na działalność upowszechniającą naukę.

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Introduction

In 1886 Dr Julius von Wiesner, professor of botany at the University of Vienna, established the scientific analysis of paper, built on examination through the optical microscope, chemical tests and identification of the fibre through comparative analysis with botanical reference material of plants. He was one of the pioneers in the field of microscopy, plant anatomy and plant physiology between 1886 and 1911 and was involved in the scientific analysis of ancient Arab paper, European paper and of archaeological paper excavated in East Turkestan and Central Asia, with a focus on the identification of the fibres used. The history of European paper had until then been built entirely on palaeographic interpretation of written sources and Wiesner's method completely changed the history of paper. His last analysis of paper from 1911, presented here, illustrates the development from 1886 of his analysis and examination of hundreds of Arab, European, East Turkestan and Chinese paper samples from archaeological excavations along the Silk Road. Among the fragments of manuscripts from Sir Marc Aurel Stein's second expedition to East Turkestan and Dunhuang, were archaeological samples of paper dated to a period close to Cai Lun's report of a new writing material in 105 CE. In Wiesner's analysis of these very early paper fragments not only are the results of his microscopic examinations and identification of the fibre described, but also and for the first time his macroscopic examinations of the paper itself, where evidence of the technology bolsters his hypothesis regarding the origin of rag paper in China and his conclusion and evidence.

V. Treatise. Julius von Wiesner *A new contribution to the history of paper – about the oldest rag papers discovered until now* (presented May 10th, 1911)

p. 1 At last the history of paper, especially of paper production may be based on solid groundwork now the indispensability of the most robust scientific protocol for the material analyses has been realised. We must establish what might be understood from the written sources about the technology of paper production, where possible, through a scientific control essential in understanding the processes of early paper production. Establishing the dates of papers is of course the preserve of historical research. A more profound understanding of the history of paper may therefore be achieved through close collaboration between historians and scientists. While we relied on historical studies alone to establish the history of paper, errors occurred in relation to

basic questions and in a number of details. A thorough examination based on the historical and scientific standards should produce irrefutable evidence.

p. 2 We only have such certainty regarding Arab and European rag paper and not the history of the origin of Chinese rag paper. Although the scientific analysis presented here supports the historical research, there is much more to discover. Until the end of the 1880s it was believed that rag paper was a German invention from the beginning of the fourteenth century at the latest. Paper was used only as a writing material at that time in Europe, but other data claimed that paper went as far back as the eleventh or even the tenth century. This also applied to other European nations, especially Italy, which may also be where rag paper was invented. Examination of the paper from the collection of the papyrus of Archduke Rainer for the first time made possible a scientific analysis combining historical and antiquarian analyses. This work established that the production of European rag paper may be traced to Arab origin in the eight century, whence it spread via Spain and Italy to the rest of Europe[1]. The Arabs did not, however, invent paper. It has been long established that the Arabs learned to produce genuine paper from Chinese prisoners of war. It is important to establish the bridge between the Chinese and Arab paper in order to discover the beginnings of the production of rag paper.

p. 3 Until the end of the 1880s the history of Chinese paper was perceived at the same preliminary level as that of European paper. Aside from my own above-mentioned analysis of old Chinese paper, the history of Chinese paper is based solely on written sources rather than the material analysis of samples. This one-sidedness means that many results in this research must be considered presumed; only some will be considered certain. Cai Lun's development of paper production from plant fibres seen as an important invention and dated to the year 100 CE must be considered reliable. Édouard Chavannes[2] would give 105 CE as the more precise date of Cai Lun's invention (as Chavannes writes in his studies of paper made from plant fibres).
Among the information from the specified sources that Chavannes relies on there are attempts to indicate that Cai Lun used the bark of wood, rags ('de vieux chiffons de toile') and fish nets ('filets de pécheurs') as raw materials for the production of paper. The only bark of any significance was the bast

[1] J. Karabacek, *Das arabische Papier. Mitteilungen aus der Sammlung Papyrus Erzherzog Rainer*, Bd. II und III (1887); J. Wiesner, *Mikrosk. Untersuchungen der Papiere von El-Faijûm. Ebendaselbs*t, Bd. I, p. 45 ff (1885); Ferner J. Wiesner, *Die Faijûmer und Uschmûneiner Papiere. Ebendaselbst*, Bd. II und III (1887).

[2] *Les livres chinois avant l'invention du papier*, par Édouard Chavannes, "Journal Asiatique", Paris, Janvier-Février 1905.

from the paper mulberry tree (*Broussonetia papyrifera*). References to analyses of the material are lacking, but Chavannes cites Stanislas Julien and Paul Champion[3], who refer to Chinese sources.

p. 4 Special emphasis has been laid on the fact that these different materials were prepared unmixed and that the quality of the raw materials caused differences between specific types of paper. Chavannes, however, was unable to confirm this information through written sources. The results of the following research contradict this information regarding the material quality of ancient Chinese papers. That Cai Lun should have used fibres from the paper mulberry in combination with Chinese hemp, the bast fibres from *Boehmeria nivea* and rags for paper production are beyond doubt. According to Karabacek paper production from bast fibres from *Boehmeria nivea* began under the reign of the Emperor Kao-Tsung (649-683; 1. c. p. 28). Karabacek reports that in the beginning the Chinese produced their paper entirely from bast from the paper mulberry tree and not until much later, after 940 CE, began producing it from rags. At that time rag paper was used by people throughout Arab cultures and they had their own efficient methods of production (Karabacek 1, c, p. 31). Information about earlier Chinese writing materials from plant fibres agrees on only a few points. Chavannes dedicated the above-mentioned article to this subject. That before the invention of true paper the Chinese engraved characters on bamboo slips with hot needles, as is widely acknowledged, is not mentioned here. Silk, bamboo, pure wood (tiny wooden tablets) were the only writing material to have been mentioned before the Cai Lun (information that also is to be found in numerous other written sources). Small wooden tablets with Chinese characters evidently existed, as is supported by recent excavations in East Turkestan. The literature makes mention of nothing to my knowledge about the nature of the material. Nor have I found the opportunity to examine these small wooden tablets. If they actually are partly produced of the solid tissue of the bamboo, as is claimed by Chavannes, it should be easy to demonstrate.

p. 5 It should of course be easy to establish whether real wood was also used in their preparation. It would, however, be more difficult to investigate the types of wood used.
The existence of silk paper would, to my knowledge, even today be impossible to establish by dint of examination of the material. The above-mentioned sources

[3] S. Julien et P. Champion, I*ndustries anciennes et modernes de l'empire chinois*, Paris 1869; see also Hirth, *Die Erfindung des Papiers in China. Chinesische Studien*, Bd. 1, München 1890 und Blanchet, *Essay sur l'histoire du papier*, Paris 1900.

provide the relevant information to show that these silk papers were produced from left-over silk (bourre de soie), i.e. the parts of the silk cocoon left when the silk cocoons are reeled. Such left-over silk was also long used in the production of cheaper silk products, thus representing a more expensive raw material than the tiny wooden tablets. These silk papers would have formed a closely interlaced material, probably produced through pounding the raw material. The oldest information about such silk papers originates from approximately 300 BCE. Silk paper and the small wooden tablets quickly became obsolete with the introduction of Cai Lun's paper, according to Chavannes. Silk paper, especially, quickly ceased to be produced not only because of the costliness of the raw material, but also because the heavy wooden tablets could not compete with the light paper of plant fibres. In addition to the above-mentioned raw materials the Chinese would also have used cotton in the production of paper, according to German and Italian palaeographers. They assumed, albeit without concrete evidence, that cotton paper (*charta bombycina*) would have come before rag paper and that the Chinese were the inventors of this paper. Chinese written sources, however, contradict this and all paper formerly described as cotton paper due to its long-fibred structure transpired upon microscopic analysis to be rag paper.

p. 6 Karabacek dedicated[4] a special chapter to the origin of the rag paper legend (i.e. a paper made of raw cotton). Cotton as a raw material in paper production is thus completely refuted[5]. We shall now look at whether past examinations of material have contributed to addressing whether the raw materials used for the production of Chinese paper may shed light on the link in between the Arab production of rag paper and the Chinese production of rag paper, and whether material analyses might confirm this. Even were there to be

[4] 1. c. p. 43 ff.

[5] From what I know of the latest palaeographic literature, it seems that the old belief in the existence of a cotton paper had been relinquished. I felt even more emboldened in my opinion when Wattenbach, the chief voice behind the theory of the existence of a *charta bombycina*, relinquished his view after having read the antiquarian studies of Karabacek and my analysis of the material. I presume that, according to the renowned pharmacologist, Professor von Rudolf Kobert's dissertation (Zeitschrift für angewandte Chemie und Zentralblatt für technische Chemie 1910, p. 1249 ff.) the legend of the cotton paper has resurfaced in the work of Alfred Gercke and Eduard Norden: Einleitung in die Altertumswissenschaft (1910-1911): The monasteries such as for example Monte Cassino had long been cultural centres. A number of copies of antique works transferred from old papyrus rolls were made to durable parchment bindings that went on in the twelfth and thirteenth centuries occasionally to replace books made of bad cotton paper *(charta bombycina)*. Professor Kobert had the opportunity to study a number of papers from this critical period, among them papers from Khotan and Turfan, and concluded like me that cotton paper belonged to the realm of legends. Professor Kobert's dissertation that essentially confirms my analysis of Arab and European papers titled "Über einige echte gefilzte Papiere des frühen Mittelalters" formed the basis of paper that was presented at the main meeting of the association of German chemists in Munich on 20th May 1910.

no doubt that the Chinese were the masters of Arab papermakers, it remains to be established beyond doubt that the Chinese had already taught the Arabs to produce paper from rags.

p. 7 In spite of thorough antiquarian studies, further documentation that the Arabs learned from the Chinese to produce paper from rags has been unforthcoming. Analysis of the material from which precisely dated paper is composed will most likely yield reliable results. The ancient paper manuscripts at the British Museum, excavated in East Turkestan, were sent to me in convenient samples for analysis at the behest of Professor Hoernle in Oxford[6] and later I also received Marc Aurel Stein's important discoveries for paper analysis[7].

Dr Dimitri Klementz reported on most of the excavations in East Turkestan, as is confirmed by a report from the Scientific Academy in St Petersburg under the title "Turfan and its ancient periods" (Turfan und seine Altertümer, Petersburg 1899). As far as I know, there is no material analysis in the Russian section of the papers discovered here. Professor Kobert's above-mentioned report, however, tells us that the German excavation commission may have transferred the paper material from Turfan to him for scientific analysis. The results that Kobert obtained from the raw material of the paper concur entirely with my results.

My analysis of papers from East Turkestan has yielded the following results. Analysis of the papers from between the fourth and eight centuries by our calendar suggests that the most important raw material for Chinese paper was bast fibres from dicotyledonous plants, primarily bast fibres from the cortex of the paper mulberry tree. Other bast fibres, however, also occur especially from Chinese hemp (ramie or China grass, *Boehmeria nivea*) [ed. Chinese word for hemp is used for all groups of hemp-like fibres].

p. 8 Fibres from other dicotyledonous plants were also in evidence, partly belonging to other kinds of *Boehmeria* that we have been unable until recently to identify botanically.

As previous analyses suggested, cotton was not in evidence (see above p. 6). Nor was silk ever found in these papers, but it must be born in mind that this does not mean that the Chinese could not have used it in paper production. It only bears out historical research, which shows silk to be missing from the paper

[6] See further about this in my dissertation "Mikroskopische Untersuchung alter Ostturkestanischer und anderer asiatischer Papiere nebst histologischen Beiträgen zur mikroskopischen Papieruntersuchung". Mit 18 Textfiguren. Denkschriften d. kais. Akad. D. Wissensch., math.-nat. Klasse, Bd. 72 (1902).

[7] J. Wiesner, *Ein neuer Beitrag zur Geschichte des Papiers. Diese Berichte*, Bd. 148 (1904).

from between the fourth and eighth centuries because it is demonstrated that in the year 105 CE, or soon thereafter, the production of paper from silk ceased and yielded to paper made from plant fibres.
Cai Lun's process did not immediately concentrate on the use of bast fibres from the paper mulberry tree. In the beginning different plant fibres were used, among which were also to be found the fibres of a variety of types of bast from dicotyledonous plants, until eventually it was realised that the fibres from the paper mulberry tree were especially suitable for paper production. The condition of the fibres in the ancient Chinese papers helps us to determine that the method used in separating the fibres had not been homogeneous, but that the fibres in the first period of Chinese paper production were extracted mechanically by dint of pounding, and later through a chemical procedure (maceration). For a period a mixed mechanical-chemical procedure seems to have prevailed, until finally the preparation of the paper through the maceration of fibres from the cortex of the paper mulberry tree began to predominate. One examination of the material yielded an important result that contradicts the view that emerges from a study of exclusively historical data, i.e. that the Chinese still only used pure, homogeneous material for their paper production.

p. 9 One may find bast cells from a variety of different plants in one paper. My discoveries were confirmed by Kobert's later examinations of paper from Turfan and Khotan. Special importance may be accorded my documentation of the fact that fibres from rags, especially rags made of Chinese hemp, are present alongside macerated raw fibres from the paper mulberry in one and the same paper. This discovery therefore suggests that the Chinese in fact already included threadbare, worthless textiles in paper production. It may also be deduced from this discovery that the fibre pulp extracted from the rags as a surrogate was mixed with the freshly macerated fibres produced from the bast of the paper mulberry tree. I had the opportunity to demonstrate the use of rag-fibre mass as a surrogate in several old Chinese papers from between the fourth and eighth centuries. We doubtless have the Chinese to thank for the original use of rags in the production of paper. This is not to claim, however, that the Chinese were alone in producing paper from rags. I have never found an ancient Chinese paper that clearly indicated that it had been produced as pure rag paper. With this dissertation I shall seek to establish that the Chinese produced pure rag paper as early as at the beginning of the age of paper production. This is confirmed by the relevant papers, dated to the same time. The fact that the Arabs adopted the art of producing genuine paper from the Chinese has already been established.

p. 10 It remains unclear whether, having learned the principles of the production of true paper [ed. with an irregularly intertwined fibre structure different from textile] from the Chinese, the Arabs devised the idea of producing paper from rags completely independently, or whether they were prompted by the Chinese to produce paper purely from rags. Even if the older Chinese papers consisted solely of raw plant fibres directly extracted from the plant and still unused in weaving, the Chinese also went on to produce paper containing rags as surrogate in precisely this critical period in the eighth century, when the Arabs began production. In Persia, where the Arab production of paper began, bast fibres from the paper mulberry tree, the most important raw material in Chinese paper production, could not be had due to a lack of the trees. The Chinese papermakers who had passed on the knowledge of papermaking methods to the Persians may well have recommended the Persians try to use a surrogate material as raw material. Nor is it out of question that the transition from Chinese to Arab paper production happened as the above alternative describes. Chinese papermakers may first have tried to extract the bast fibres from a number of trees related to the paper mulberry tree, such as the Persian (*Broussonetia papyrifera = Morus papyrifera*) or the black mulberry tree (*Morus nigra*)[8]. In order to resolve this, material examinations of papers from the early period of Persian Arab paper production had to be carried out first.

p. 11 According to Karabacek Arab paper production began in the year 751 CE. The analysis of the papers dated to the same time does not confirm this because there are no Arab papers dated earlier than the year 796 CE. The transfer of Arab paper production from the Chinese cannot therefore be concluded. What we know today, however, of Chinese papermaking methods suggests that the Arabs learned about the preparation of true paper from the Chinese and were guided by them in the use of rags in the production of paper A description of an old Chinese paper that without doubt is produced entirely of rags follows. There has hitherto been no proof of Chinese paper of this kind. Dr Marc Aurel Stein sent me this highly important paper to examine together with many other old Asian papers. It originates from his second expedition between 1906 and 1908[9].

The paper arrived in January last year and Dr Stein wrote to me about it on 18th of January: "the sample sent (T XIIa ii 1) comes from a discovery of important documents in a script similar to Aramaic, but in a completely unknown language, which I found in a decayed Limes garrison, west of Dunhuang. The Chinese wood documents discovered together with the paper are dated to the first years CE".

[8] Wiesner, *Mikr. Unters. Ostturkestan. Papiere*, Denkschriften, p. 620.

[9] "Exploration in Central Asia", 1906-1908, "Geographical Journal" for September 1909.

p. 12 In the same letter we find: "In the second century CE the garrison must already have been in ruins". It is not mentioned or could not be further established when the watch-tower was abandoned. In the paper T XIIa ii 1ª you have a find originating at the latest from the second century CE, perhaps from the beginning of the second century, from the period when the Chinese invented paper from plant fibres. This paper originates from a period not so distant from this date and may even be older. In a later letter (Oxford, 2nd March, last year) he tells us more accurately that the Chinese documents written on wood originate from between 3 and 20 CE and are precisely dated. "For archaeological reasons", he goes on to inform us in the letter by posing the question, "would I *a priori* assume a similar age for the paper document, if it did not conflict with the confirmed age of 105 CE of Cai Lun's invention of plant fibre paper". If this consideration is valid one may have every reason to accept the year of Cai Lun's invention of paper made from fresh plant fibres. In T XIIa ii 1ª we are therefore probably dealing with a paper no older than Chinese plant fibre paper. As far as we know, this could only have been silk paper, but it remains to be confirmed by microscopic analysis and we must also presume a paper of plant fibres originating from the first period paper was made from plant fibre to be of great importance. It has been established beyond doubt that Cai Lun produced paper from paper mulberry bast fibres. It seems to be certain that Cai Lun also used Chinese hemp and rags in the production of paper. In which order he added these raw materials in the production process is unknown. The paper findings discussed certifiy that rags were used early in the production of paper. It is likely that the very first attempts to produce paper were made using rags.

p. 13 I decided to study the texture of this paper. The sample sent to me for analysis was without writing, similar to the other samples I had received. Since I did not need paper with writing in order to analyse the material, Dr Stein understandably retained the papers bearing text of importance for archaeological research and only let me have such blank paper with no writing on it. My sample was 10 cm in length and 4 cm in width. It was noteworthy that this paper showed no starch sizing. The earlier-mentioned paper samples show the sizing. According to the examinations so far published concerning starch sizing in Chinese paper dates this invention as early as the seventh century[10]. The lack of starch sizing in this paper seems to suggest a great age because the later Chinese papers were nearly all thoroughly sized with starch and, according to my latest research, starch sizing began earlier than we have

[10] Wiesner, *Mikr. Unters. Ostturkestan. Papiere*. Denkschriften, 1. C. see further this report, Bd. 148, p. 5.

hitherto presumed[11]. In reflected light our paper appeared homogenous, closely joined together, lustreless and of a slightly yellowish colour, and when torn, long fibres were revealed.

p. 14 The impression of the paper, however, in transparent light was surprising. While the sample looked homogeneous and paper-like in reflected light, it looked transversely and lengthwise striped in transparent light. It gave the impression of a slightly damaged structure. This texture suggested the method that might have been used in the production of the paper. Two possibilities come to the fore: firstly, a portion of long-fibred raw material may have been used, perhaps the half-pounded bark of plants (bast) that could be used during the sheet formation. A greater degree of homogenisation of the writing material might thus have been attained instead of mixing the half-pounded bast material in such a way that the lengthwise fibres would dominate. Imagining that the fibres in the papers produced near the earliest period of paper were originally intended to be intertwined and entangled in the paper structure, one may remember that during the production of the ancient papyri it was foreseen to bind the cut strips of the papyrus plant in mutual perpendicular directions. The other possibility is that the crossing direction of the fibre is due to a real woven structure. In other words, the paper was made of a textile by means of which its thin surface of woven character was preserved in a more or less damaged condition. This idea implies that the crossing fibres are not bundles of bast fibres, but threads of yarn. This observation has now been confirmed.

p. 15 Both the fibres along the lengths and those across the widths of this paper are heavily spun threads of yarn. A thread is easily recognisable through its twist-marks visible on the fibre texture and thus completely excludes the possibility of the presence of strips of raw bast. It is remarkable, however, that such marks are not noticeable on each thread of yarn. Examination of the threads both lengthwise and across reveals that they are indeed badly damaged in many places, but the nature of the spun threads of yarn is also recognisable in individual places and often in long pieces.

[11] Among the ancient dated papers that Dr Marc Aurel Stein had procured for analysis of the material there are some sized with starch. The oldest Chinese document with the signature LA.VI ii, Nr. 904 in this group from the ancient monuments north of Lop-nor is precisely dated to 312 CE. According to this theory, the starch sizing of Chinese paper goes back to the 4th century and was therefore used two centuries after the invention of plant-fibre paper. The history of this important starch sizing of paper has been of great interest to me and I intend to discuss it in more detail in a later monograph.

p. 16 The intention was to remove the original structure of the textile and transform it to a homogeneous writing material by dint of a pounding process. Thoroughly pounded masses of fibres were used as fillers to achieve an even more homogeneous material. Through microscopic examination of the paper plentiful substances of fine fibres were found between the more or less completely destroyed threads largely corresponding to the yarn. The origin of the fibres found in this paper will be discussed later. Here I would conclude that this study of paper T XIIa 1* shows the oldest attempt to transform a textile into a writing material. Today the rags are triturated as finely as possible to obtain tiny fibres which may be bound closely together through scooping or similar procedures, and thus produce thin sheets of true paper. To what extent rags immediately disintegrated and intertwined during the scooping into paper is uncertain, but such a stage would gradually have been reached. This paper sample hints at a possible pre-step to the paper production. Our sample consists of partially pounded textiles, where the still recognisable threads of yarn form the skeleton of the paper, embedded in a short and fine fibred substance of fibres. This characteristic of the writing material suggests that in their search for a thin, light writing material to replace the compact wooden tablets the Chinese transformed thin linen and canvas textiles into writing material. The textiles may have been pounded in such a way as to stop short of completely destroying the weaving structure. The intention would have been to use the binding of the threads in order to preserve the desired shape of the surface of the writing material. It was impossible, however, to write on the half-pounded textile because it was too thin and therefore a filling of completely pounded fibres would be added to the skeleton of yarns until it was homogeneous.

p. 17 How had they imagined this mixing of the threads of yarns with fresh plant fibres? Fine fibres were clearly deposited in an aqueous solution on the textile. The threads of yarn may have been mixed in such a way as to render a homogeneous material suitable for writing and then through pressure, glazing and drying be more suitable for writing. If this is correct, this type of paper production would already have led to the scooping method. It would then be clear that a further step in the production was necessary and that the textile needed to be triturated in a similar way and the substance of fine fibres united through scooping. The following advantages were thus achieved:
1. One did not need good, well preserved linen textiles for the production of the writing material. One might use materials already used as textiles (rags) for paper production because it would only be necessary to extract the small, fine fibres that could be produced just as easily, if not more so, from rags than from good textiles that consisted of stronger threads of yarn.

2. The manufacture of paper from a substance rich in fine fibres through scooping resulted in a more homogeneous and therefore better writing material than that from a substance of half-pounded textiles that by covering with a fine substance of fibres only achieved a superficial aspect of homogenisation.
3. Paper entirely manufactured through the scooping of triturated rag substances in two directions clearly had to be considered: not only was it better, but also much cheaper to produce.
Were this to be true as described here, it would be understandable that this hypothetical method of the first production of paper of good linen-woven textiles was quickly abandoned.

p. 18 These hypotheses of the pre–step to rag-paper manufacturing remain dubious because this paper fragment is a unique specimen. The other, younger papers found in the same watch-tower showed none of the characteristics described. Stripes were observed in individual cases, but they were discovered in a completely different way, a way described below, because in these last papers no threads of yarn could be discerned. Even if all these hypotheses transpire to be untenable, analyses of this paper, indisputably of plant fibres, document with certainty that even in the early period of Chinese paper production a paper of pure rag fibres existed. Regarding the sort of plant fibres of which paper T XIIa 1[a] consists, the following may be said: these plant fibres are difficult to identify because the fibres suffered considerably during the pounding. Microscopic observations show firstly that this plant fibre is completely wood free, as is confirmed by the acknowledged cellulose detection reaction. Cotton was not found; neither were flax nor hemp fibres (from *Cannabis sativa*). The fibres are even bast cells. Individual and rather intact, preserved fibre fragments (up to 2 cm in length) suggest in structure and dimensions an East Asian nettle fibre (*Boehmeria urtica*). It is most likely that this fibre corresponds to Chinese hemp (*Boehmeria nivea*) that has been cultivated in China since antiquity and is used today as *tschou-ma*. It has also been cultivated until the present-day in many countries in warmer climes and also used as China grass, ramie etc. because of its importance for the European industry[12].

p. 19 The paper of our sample consists of strings and a short- and fine-fibred groundmass. These two constituents make the paper appear quite homogeneous, at least in reflected light. In transparent light, however, it is possible to discern the structure. Since it is possible here to differentiate between strings and groundmass, the question arises whether the former consist of the same plant

[12] See here Wiesner, *Rohstoffe des Pflanzenreiches*, 2. Auflag, Leipzig, Engelmann. Br. II (1903), p. 318 ff.

fibres as the latter. Since no such a difference between the string fibres and the fibres of the groundmass have so far been discerned it seems certain that only one sort of fibre is present and the filling, like the strings, comes from rags. A starch sizing could not be detected in the paper. I have demonstrated that this type of sizing was devised by the Chinese to make the paper fit for writing and later taken over by the Arabs[13].

Our paper may be demonstrated to be completely free of starch or dried starch glue. It seems characteristic of our paper that it is half fluid and the coarser fibres make it irregularly fluid. These two peculiarities will be briefly described here. If a small drop of water is added to a modern, homogeneous pronounced filtering paper, it immediately spreads evenly across the paper, leaving a round transparent blotch of water. If, on the other hand, a small drop of water is added to modern paper, completely sized with starch, it will not be absorbed, but will evaporate without spreading. If a small drop of water (of an average of between 3 mm and 5 mm) is added to our paper, it will spread well on the surface, but less quickly than on modern filter paper. It takes between 150 and 230 seconds for it to be completely absorbed and a transparent blotch of water is left on the paper.

p. 20 It must also be noted, however, that the drop of water would not spread regularly over a circular area, but a quite irregular indented area would be achieved. The non-homogenisation of the paper would result in an irregular spread of water and depend primarily on the fact that coarse fibres in the paper interact with fine, short fibres. The reason the drops spread so extraordinary slowly in our paper, in spite of the lack of provable sizing, is uncertain. Before an explanation of this peculiarity is ventured, it should be mentioned that this half-fluid characteristic of the paper offered the advantage that it was possible to write on it with a thin liquid, whereas it was only possible to write on fluid paper with a very thick and therefore less fluid liquid, such as Indian ink. On our paper, T XIIa ii 1[a], however, it was just possible to write carefully and in thin lines, even with modern thin fluid ink, such as the so-called Alizarin ink. Remarkable is the unusual fine, grind mass present in our paper that occurs between the fibres and partly attaches to them. I have mentioned above that a great deal of atmospheric dust is detectable in ancient papers[14].

Only part of this fine-grained mass, chiefly consisting of mineral substances, is traceable back to atmospheric dust. A large part of the substance seems to belong to a mineral filling that perhaps holds back a heavy fluid and keeps

[13] Wiesner, *Ostturkest. Papiere*, 1. C. p. 630, 631. The same, *Ein neuer Beitrag zur Geschichte des Papiers*.

[14] *Die Faijûmer und Uschmûneiner Papiere etc.*, pp. 52-53.

it on the surface of the paper. A tightening of the paper may have been applied through certain mechanical procedures (glazing, heated plates, etc.) limiting the "fluid" and rendering the paper completely suitable for writing.

p. 21 Other papers with writing were found in the old watch-tower, from which the above paper originated, and Dr Stein handed over two of these to me for material examination. One of them bore the signature T XIIa ii 1 and the other the signature T XIIa ii 4[15]. Paper T XIIa ii 1 represents a more developed technology of paper production than paper T XIIa ii 1ª. They agree substantially with the last, consisting of bast cells of the species of *Boehmeria.*

p. 22 Both are clearly scooped papers, furnished with characteristic watermarks originating from the screen of the mould that was used in the scooping of the paper[16].
The raw material for both of these papers consisted entirely of rags that were separated through pounding them into fine fibres. Distinct threads of yarn could no longer be found in these two papers. It is understandable that only traces of threads of yarns were present in these papers because the preparation aimed at an extensive separation, and the binding of the fibres occured during the scooping of the paper. The watermark of T XIIa ii 1 consists of parallel stripes. It is in modern parlance a laid paper, but of a relatively irregular though fine structure. In the preparation of this paper a screen that consisted of parallel fine sticks (or strings, possibly even metal wires) would have been used. The paper XIIa ii 4 has a more complex watermark because another stripe, combined with the parallel rips, over a much greater distance crosses the stripes. The screen that served for the scooping of this paper was more complex in its construction than that used for the production of the first because it consisted of two crossing systems of sticks. Both papers nevertheless represent a much improved production than that of the paper T XIIa ii 1ª. In the production of these two papers a simpler, but more logical process had been used than that that could have served for the production of paper T XIIa ii 1ª. These two papers are also "half-fluid" as described above. On these papers it is also possible to write in relatively fluid ink, even with the modern alizarin ink.

[15] The manuscript in question remained in England and was at my request on behalf of Dr M. Aurel Stein photographed in transparent light at the University Press, Oxford. The papers T XII a ii 1 and T XIIa ii 4 referred to in the text show exactly the same watermarks as paper T XII a ii 3.

[16] Here the word "watermarks" is used in a wider sense, i.e. as a term for the thinned places of the paper through which light penetrated and which appeared transparent. The watermarks referred to in the text are all determined by the screen of the mould. The paper appeared finely striated (laid) if the screen consisted of mutual parallel sticks, threads or wires; crossing lines or stripes would appear as watermarks (in our terms) in the paper, if the screen consisted of crossing sticks or the like.

p. 23 These two papers are, however, less homogenous than modern papers because a drop of liquid will not pool regularly into a circle, but more likely into an irregular indented area. The non-homogenisation of the fibres is responsible for this. Coarser fibres also interact with finer fibres. The breaking up of the rags would still have been done roughly through pounding. Because these papers were considered "half-fluid" the question arises which method yielded this quality. Hereafter one may reflect on a kind of glue. It is certain that they have been neither sized with starch nor glued with animal glue. Microscopic examination has yielded some clues regarding the discovery of the nature of the glue, but both of these two papers caused huge difficulties. Not only did the fibres exist in states of heavily mechanical treatment, but there was also a presence in both of fibres of a number of other compounds. Their origin might be settled, but their connection to paper production might not always be documented. Similarly to many other rag papers traces of silk and yellow coloured woollen hairs were found together with ferment organisms of various kinds, sporadically remarkable big masses of a hypha. Sometimes elements of lichen, as well as gonidia as hyphae were observed (more plentiful in T XIIa ii 1 than in T XIIa ii 4). The placing and reproduction of bacteria in the papers are unremarkable, but the presence of lichen elements suggests that lichen might have been used to size the paper. Such lichen sizing has already been documented in an old East Turkestan paper[17].

p. 24 The manuscript T XIIa ii 4 has already been treated from an antiquarian and linguistic point of view by A. Cowley[18].
Cowley's paper also furnishes us a picture of the manuscript and discusses in more detail than here the place the document was found and also describes the place where the two other papers treated here were found.

Conclusion

Until the end of the 1880s there was general consensus that rag paper was a European invention devised at the end of the thirteenth or the beginning of the fourteenth century. My scientific examination of ancient papers in the Papyrus Erzherzog Rainer collection demonstrates in complete concurrence with the results found in J. von Karabacek's historical-antiquarian studies that European paper production developed from Arab paper production. According to von Karabacek's precise calculation, it began in 751 CE.

[17] Über ostturkestanischer Papiere in den Denkschriften, 1. c., p. 615 ffd.

[18] A. Cowley, *Another unknown language from Eastern Turkestan*, "Journal of the Royal Asiatic Society", January 1911.

Even were there no longer to be doubt that the Arabs were taught by the Chinese in the art of producing true paper, the question remains whether the Arabs were the first to produce rag paper or whether the Chinese also taught them to use rags in the production of paper. Historical research has until now yielded no unambiguous answer to the question. Concerning the finds of manuscripts made by the English in East Turkestan, earlier material examination demonstrates that the Chinese had already used rags in the production of paper, but it may only be established that rags were used as a substitute for more precious papermaking fibres. In fact this remains to be discovered through future analyses of paper.

p. 25 Among the papers Marc Aurel Stein carried with him from his last Central Asian Expedition (1906–1908) and handed over to me for examination was one of great importance (T XIIa ii 1[a]). It was located next to precisely-dated documents in a ruined watch-tower in old Limes, west of Dunhuang. The watch-tower had lain in ruins since the second century CE and it may therefore be assumed that this paper belongs to the period of time when paper was made from plant fibres, then considered Cai Lun's invention from the year 105 CE. This study shows that as early as during the first period of Chinese paper production, paper made from plant fibres was manufactured exclusively from rags. In reflecting light this paper looks quite homogenous and papery. In penetrating light, on the other hand, it looks to be criss-crossed with a textile-like structure. The stripes appear to be threads of yarn. This textile, clearly altered through heavy pounding, appears enveloped in a mass of fine fibres. The whole paper, threads and groundmass, consists of bast cells of the same sort of plant, a plant of the species *Boehmeria*, that through pounding of the original textile was separated into a rather altered form. The textile-like character of the structure of this paper suggests that an attempt had been made to produce thick and homogeneous material suitable for writing at the time plant-fibre paper was developed. This was achieved through the pounding of textiles, where its flat character depended on the connection of the threads of yarn and the filling of fine separated plant fibres, a method of scooping, glazing and drying. It should here be indicated that, not only were very different raw materials used at the beginning of paper production (using plant fibres), but different methods were also tried until eventually a satisfactory method was reached.

p. 26 Several other papers found in the same watch-tower appear to be rag papers, although only traces of threads of yarn, however, can be discerned in them. These two papers already bear the character of filtered paper and seem likely to be of younger date back earlier than the paper T XIIa ii 1[a].
The following may be concluded:

1. From the Middle Ages until recently rag paper was the most important and only paper used. It was invented by the Chinese.
2. As early as during the first period of paper production using plant fibres the Chinese, and later the Arabs, mastered the production of paper entirely from rags. Chinese rag-paper production is therefore approximately six hundred years older than Arab rag-paper production.
3. The use of rags as raw material in Chinese paper production verifiably lasted until the eighth century, when rags were still used as a substitute for more precious fibres.
4. Because the Chinese produced pure rag paper long before the Arabs and were verifiably still doing so during the period when Arab production of rag paper had begun, the Chinese may be said to have taught the Arabs the methods for producing rag paper. It is beyond doubt that the Arabs not only learned the method from the Chinese, but that they also adopted the use of rags in paper production.

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