TECHNOLOGY, TREATMENT, AND CARE OF A CHINESE WOOD BLOCK PRINT

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Fig. 1: "The Victory of General Liu's Army", colored Chinese wood block print; before treatment. From the Anthropology Department, National Museum of Natural History, Smithsonian Institution

ABSTRACT

This article

- summarizes literature on Chinese papermaking technology and Chinese paper fibers;
- characterizes the properties of modern handmade Chinese *"Hsuan (Xuan)"* and *"Pi"* papers (used in Asian Painting Conservation Labs), through an analytical study utilizing
    - EDS/SEM imaging (for morphology of fibers such as straw containing phytoliths),
    - colorimetry (for discoloration before-and after aging),
    - zero-span tensile testing (for physical strength), and
    - pH (for chemical quality); and
- relates the findings to the development of a conservation treatment for a Chinese wood block print.

INTRODUCTION

Although numerous articles about the technology and treatments of Japanese wood block prints and papers have been published in English[i], little has been published about the technology and treatments of Chinese wood block prints and papers, although a few related references exist[ii]. A Chinese wood block print (See fig. 1), which had been severely damaged (it had been crumpled up, which caused extensive splits of the support), provided an opportunity to investigate the history and technology of Chinese paper in order to aid treatment development for the print[iii].

The condition of the print was extremely puzzling, posing two questions for which clues to the answers were sought. The first question was: "Why had the print been crumpled up almost into a ball?" An investigation of the print's title and place of origin, combined with a knowledge of China's history, provided one possible clue. The print was entitled "Victory of General Liu's Army." The scene appears to show General Liu's army of Black Flags in victory over the French army that was attempting to conquer the eastern provinces of Cochin China (now Vietnam). However, the Black Flags were not part of the regular Chinese army. In fact, they were a disorderly religious sect that had been expelled from China in 1863 after they tried to overthrow the Qing dynasty (1644-1911 A.D.). The scene was printed and distributed in Canton, a famous cradle of revolution against the Qing dynasty. It appears to show the French army, dressed in red, being defeated by the Black Flags, an incident that is not part of the actual historical record. Consequently, the print appears to be a propaganda piece, and this may have something to do with why it was crumpled up.

The crumpling up of the print caused extensive splitting of its paper support, and this lead to the second question: "Why was the paper so easily split?" The clue to this was discovered by a research project designed originally to compare different modern handmade Chinese papers used in the Asian painting conservation labs.

This article is divided into three parts. The first summarizes literature on Chinese papermaking history and technology. The second summarizes an analytical study characterizing modern handmade Chinese paper. The third summarizes the treatments developed for the Chinese wood block print.

1. CHINESE PAPERMAKING HISTORY

China has a long history of papermaking. Although the invention of paper has been officially credited to Lun Tsai in the Eastern Han dynasty (25-221 A.D.), recent findings of very ancient paper fragments in North and Northwest China indicate that earliest paper was made around 49 B.C. in the Western Han dynasty (206 B.C.-9 A.D.)[iv].

The following sections briefly describe some of the unusual features of Chinese papermaking technologies, materials, and specialty papers.

1.1. Chinese Papermaking Technology - Refining Techniques

The steps in Chinese papermaking technology are: 1) fermentation; 2) cooking (steaming vs. boiling); 3) bark removal; 4) rinsing; [followed sometimes by repeated fermentation; cooking and rinsing]; 5) beating; 6) cutting; 7) pulping; 8) sheet formation; 9) pressing; and 10) drying.

1.1.1. Fermentation

In Chinese papermaking technology, fermentation may occur twice. Raw materials are fermented before processing and fibers may be fermented after initial cooking, and before recooking[v]. Bamboo fibers take longer for fermentation[vi],[vii] than bast and grass fibers.

1.1.2.- 3. Cooking/Bark Removal

Steaming is a preferred way of cooking fibers for papermaking in China; boiling is rarely mentioned in the literature[viii],[ix]. The steaming process takes place twice: first for the removal of the outer bark, and second, for softening fibers before beating. An alkaline solution such as lime (calcium oxide) or wood ash (sodium or potassium hydroxide) may be added during the cooking process to remove non-cellulosic materials. One specific type of wood ash is made from burning tung tree seeds[x].

1.1.4. - 6. Rinsing/Beating/Cutting

Cooked or steamed fibers are then washed and beaten. The pulp might be cut with knives depending on regional practice[xi].

1.1.7. - 10. Pulping/Sheet Formation/Pressing/Drying

Preparation of the vat to make paper differs from region to region. Starch paste or other viscous formation aids such as Hibiscus manihot might be added to improve fiber distribution[xii]. After sheets are formed, they are brushed onto a wall with a coir brush to dry[xiii].

1.2. Chinese Papermaking Materials - Fibers

Chinese papermaking plants[xiv] have been be categorized by some authors into five different groups: hemp *(ma)*, bark *(pi)*, rattan *(teng)*, bamboo *(zhu)*, and grass *(cao)*[xv]. However, for the purposes of the present study, a more appropriate categorization of these plant groups is into 3 types of sources for fibers, as follows: 1) bast fibers (extraxylary, nonwoody) such as hemp *(ma)*, paper mulberry *(ku pi)*, mulberry *(sang pi)*, rattan *(teng pi)*, blue sandalwood *(ching tan pi* or *than pi*[xvi]*)*, etc.; 2) grass fibers (xylary, nonwoody) such as bamboo *(zhu)*, or straw including rice, wheat, etc.; and 3) mixtures of bast and grass fibers. Table 1 lists types of fibers with their Chinese names, Latin names, source, dynasty, and location. Note that paper mulberry paper was used in the Later Han (25-220 A.D.), while it wasn't until the Ming dynasty (1369-1644 A.D.) that mulberry fibers were used.

1.2.1. Bast Fibers

Hemp fiber *(Cannabis sativa)*[xvii] was probably the earliest material used for papermaking in China. Paper mulberry fiber (*Broussonetia papyferia)*[xviii] originated in the Eastern Han dynasty (25-220 A.D.). Rattan fiber *(Calamus rotang)*[xix] has been recorded from the Wei/Jin dynasty (265-420 A.D.). In the Tang dynasty (618-907 A.D.), second to hemp paper, rattan was the most widely used for government documents. However, rattan was limited to the southeastern region and eventually became extinct due to the over-harvesting of plants[xx]. Blue sandalwood fiber (*Pteroceltis tatarinowii*, classified under the elm tree family)[xxi] did not come into general use until the Ming dynasty (1368-1644 A.D.)[xxii].

1.2.2. Grass Fibers

Grasses have probably been used from before the Song dynasty[xxiii]. Bamboo fibers were used for papermaking from the middle of the Tang dynasty (618-906 A.D.). The use of bamboo fibers gradually supplanted rattan after the Song dynasty (960-1279 A.D.) because of the improvement of Chinese papermaking techniques. Bamboo paper was commonly found in the southern region of China because of the proliferation of bamboo in the region[xxiv]. Rice straw fibers *(Oryza sativa*) provide the major raw stock for wrapping paper, toilet tissue, and paper money for the dead.

1.2.3. Mixed Fibers

Mixing different fibers was a common papermaking practice before the Song dynasty[xxv]. Recent findings suggest that Chinese mixed hemp with paper mulberry fibers during papermaking in the Tang dynasty[xxvi]. The use of hemp and rattan as papermaking fibers declined after the Southern Song dynasty (1127-1279 A.D.)[xxvii]. However, mixtures composed of bast fibers/bamboo; bast fibers/straw; and bamboo/straw have dominated the Chinese paper market since the Song dynasty. Mixtures composed of blue sandalwood and rice straw[xxviii] did not became a major source of paper fiber until the middle of Qing dynasty (1644-1911 A.D.). Such paper is called *Hsuan (Xuan)* paper[xxix]. The selection of fibers for mixtures varied depending on geographic location.

1.3. Modern Chinese Specialty Papers - Used for Calligraphy, Painting, and Printing

Certain combinations of fibers have been used to produce Chinese specialty papers having specific properties conducive to Chinese calligraphy, painting, and printing. Modern Chinese specialty papers are predominantly *Pi* or *Hsuan (Xuan)* papers. *Pi* papers include bast fiber papers such as *ku pi* paper (paper mulberry paper) or *sang pi* paper (mulberry paper)[xxx]. *Hsuan (Xuan)* papers, as a generic name, include genuine *Hsuan (Xuan)* paper (blue sandalwood and rice straw) and imitation *Hsuan (Xuan)* paper (paper mulberry/mulberry fibers and grass fibers).

1.3.1. Modern Pi Paper: Paper Mulberry/Mulberry Fiber Papers (ku pi/sang pi papers)

Paper mulberry and mulberry fiber papers have been used as calligraphy/painting paper since before the invention of printing (700 A.D.). Before the Ming dynasty (1368-1644 A.D.), most paper-based materials were made of paper mulberry.

1.3.2. Genuine Hsuan (Xuan) Papers: Blue Sandalwood and Rice Straw

Genuine *Hsuan (Xuan)* paper is made of the inner bark of blue sandalwood *(Pteroceltis tatarinowii)*. During the Yuan dynasty (1279-1368 A.D.) paper became more popular as a painting substrate due to a revolution in Chinese painting techniques. *Hsuan (Xuan)* paper gradually dominated the Chinese calligraphy/painting/print paper market after the Ming dynasty (1368-1644 A.D.), because it allowed better ink-wash effects than paper mulberry/mulberry fiber papers[xxxi]. In the Ming dynasty, 100% blue sandalwood bark was used for making *Hsuan (Xuan)* paper[xxxii]. However, *Hsuan (Xuan)* paper became a mixed-fiber paper during the middle of Qing dynasty (1644-1911 A.D.). A mixture with local fibers, such as rice straw in Anhui was recorded in the late 18th century[xxxiii]. Genuine *Hsuan (Xuan)* papers are made only in Anhui province, primarily in the area of Jing Xian[xxxiv].

In general, there are three different grades of *Hsuan (Xuan)* paper, depending on the percentages of mixtures of blue sandalwood fiber and rice straw. The grades are most commonly categorized as extra-pure or super bark *("te gin")*; pure or fine bark *("gin pi")*; and cotton-like *("men lao")*[xxxv]. Other systems refer to percentages of bast ranging from 100% bast *("tran pi")*, to 70% *("qu pi")* and 50% *("ban pi")*[xxxvi]. The paper with a higher percentage of blue sandalwood fiber (extra-pure bark *"te gin"* or pure bark *"gin pi"*) is used for calligraphy and painting; the paper with lower a percentage of blue sandalwood fiber (cotton-like *"men lao"*) is generally used for printing.

1.3.3. Imitation Hsuan (Xuan) Paper: Paper Mulberry/Mulberry Fibers and Grass Fibers

Because of the limited distribution of blue sandalwood bark in China, imitation *Hsuan (Xuan)* paper was developed for Chinese painters/calligraphers/printers. Fiber mixtures depend on geographic location. For instance, bamboo was used in Fukien and Zhejiang, while mulberry was used in Hebei[xxxvii]. However, Chinese papermakers and manufacturers still referred to this type of paper as *"Hsuan (Xuan)"* paper. Anhui province is the major source of genuine *Hsuan (Xuan)* paper, but imitation *Hsuan (Xuan)* paper is manufactured in other provinces, including Zhejiang, Hebei, Quansxi, Sichuan, Yunnan, Taiwan, Fukien, etc.

2. ANALYTICAL STUDY CHARACTERIZING MODERN CHINESE PAPERS

In order to find compatible repair materials for the Chinese wood block print, an analytical study characterizing modern handmade Chinese papers used in Asian Painting Conservation labs was designed and carried out at the Conservation Analytical Lab (currently the Smithsonian Center for Materials Research and Education).

This study was limited to two major categories of paper produced by Chinese paper manufactures: bast-fiber paper (referred to as *"Pi"* paper by Chinese paper manufacturers) and mixed-fiber paper (referred it as *"Hsuan or Xuan"* paper by Chinese paper manufacturers). Both papers have been widely used in the field of Asian calligraphy, painting, and printing since the Ming dynasty (1368-1644 A.D.). They have been used as repair, lining, and backing paper in Asian painting conservation labs.

2.1. Paper Sample Selection

Paper samples were selected to represent various Chinese papermaking regions (Table 2.1). Twenty-three paper samples, from 7 regions, were collected from the following sources: the Freer Gallery of Art at Smithsonian Institution; the Museum of Art at University of Michigan; the National Palace Museum in Taiwan; the Conservation Analytical Laboratory; and John Bayne, a Chinese paper collector and researcher.

2.1.1 General Observations about the Selected Chinese Papers

Most of the selected Chinese papers had "laid and chain" lines, except for mold impressions on the mulberry paper from Yunnan (#21), which had a woven pattern. The selected *Hsuan (Xuan)* papers appeared to be less translucent than *Pi* papers. The color of *Hsuan (Xuan)* papers was in general whiter than that of *Pi* papers.

2.2. Analytical Procedures

The selected *Pi* and *Hsuan (Xuan)* papers were characterized by SEM imaging and EDS, colorimetry, tensile strength and pH, before and after aging (Table 2.2). Analysis was carried out in the controlled environment of the Conservation Analytical Laboratory (CAL) and the TAPPI room of the Research and Testing Office at the Library of Congress (LC).

2.2.1. SEM Imaging and EDS

SEM imaging of paper surfaces and SEM/EDS analysis were carried out on a Jeol JXA - 840 A scanning electron microscope with Tracore Northern TN 5502 energy dispersive X-ray analysis system (CAL). The samples were mounted on carbon stubs and carbon coated. EDS and dot maps were carried out for elemental analysis.

2.2.2. Colorimetry

The color of papers was measured with the HunterLab Ultrascan Spectrocolorimeter (CAL)[xxxviii] using the CIE L*a*b* color notation where L* represents the degree of brightness (100 white, 0 black), a* the degree of redness (positive numbers) or the degree of greenness (negative numbers), and b* the degree of yellowness (positive numbers) or the degree of blueness (negative numbers). Due to the thinness of the Chinese papers, all samples were folded to make an 8-ply sheet for measurement.

2.2.3. Zero-Span Tensile Strength

Zero-Span tensile tests were carried out using a Pulmac's Trouble Shooter Tensometer set on 35 psi as optima clapping pressure (LC). The selected samples were cut into 2 x 9 cm strips. Six measurements were taken for each grain direction and each cross direction. Thickness for all samples were measured.

2.2.4. pH

Cold water extraction pH measurement was undertaken using Fisher's Accumet model 25D pH/Ion meter (LC). Paper samples were prepared according to TAPPI method 509. For each sample, 0.25 g. of paper was extracted in 17.5 ml deionized water.

2.2.5. Artificial aging

Papers, size 8" x 10", were aged at 90 degrees C and 50% RH for 25 days in an Associated Environmental Systems HK-4116 temperature-humidity chamber[xxxix] (CAL). The quantity of selected papers required that the samples be divided into two groups for aging.

2.3. Findings

2.3.1. SEM Imaging and EDS

SEM imaging revealed the most extraordinary finding of the project. All samples showed expected morphology of paper characteristics except papers from the Anhui province of China. These papers contained a type of rice straw that had a distinctive feature not found in papers containing rice straw from other provinces.

Ninety percent of *Hsuan (Xuan)* papers from Anhui examined in this study had extremely unusual features which were eventually discovered to be phytoliths[xl]. Phytoliths are found in some grass plants. When plants absorb various chemical elements in solution from groundwater, inorganic elements such as silicon or calcium can be deposited in and between plant cells[xli]. These inorganic deposits are called phytoliths. Because phytoliths are inorganic, they resist decomposition. When plants tissue decomposes, phytoliths are released into the surrounding environment and maintain their morphological integrity. Such released phytoliths become microfossils of the plants, and this has provided valuable information in archaeological research. There is much published about phytoliths in archeological literature but not in paper conservation literature. The different types of phytoliths found in our paper samples, such as sheet elements, usually formed on epidermal surfaces, and a long cell appendage[xlii]. EDS indicated that silicon was a major element of phytoliths in most of cases, along with calcium distributed in specific areas of the phytolith. It is possible that inorganic phytoliths might interfere with or otherwise affect fiber bonding during and after sheet formation, since it was these very Anhui papers that appear to have the lower average tensile strength both before and after aging.

SEM imaging revealed that the papers were primarily bast and grass fibers. Different types of paper fibers such as epidermal cells, parenchyma cells, vessel element and woody fibers were apparent. For one Anhui paper, SEM/EDS revealed another unexpected feature, titanium, which can be used as a brightener and opacifier, was found in #8. In general, *Hsuan (Xuan)* papers appear to be less homogeneous and shorter than *Pi* papers.

2.3.2. Colorimetry

The data of the aged samples are shown in Tables 2.2 to 2.5. Zhejiang *Hsuan (Xuan)* paper (#11, 12, 13) was discolored much more than the Anhui *Hsuan (Xuan)* paper. *Pi* papers from Yunnan (#21) also discolored dramatically.

2.3.3. Zero-Span Tensile Strength

The results of zero-span tensile tests (Tables 2.2 to 2.5) show that the loss of physical strength appear not to be significant (based on estimated standard deviation) after papers were aged, perhaps due to the weakness of fiber strength to start with. Findings indicated that the strength of *Pi* (#1-8) is greater than that of *Hsuan (Xuan)*[xliii](#20-3). This is also confirmed by the table of aspect ratio of plant cells (ratio of Length/Breath)[xliv] (Table 3). The aspect ratio of rice straw *(Oryza sativa)* is much smaller than bast fibers. The aspect ratio of blue sandalwood *(Pteroceltis tatarinowii)* is smaller than most bast fibers. This might be an additional explanation for physical weakness of *Hsuan (Xuan)* paper.

2.3.4 pH

The results of pH value are shown in Tables 2.2 - 2.5. Most of the modern handmade Chinese *Hsuan (Xuan)* papers tested alkaline before and after aging except the *Hsuan (Xuan)* paper from Zhejiang (#11, 13) and from Quansxi (#14). The high pH value of these Chinese papers may due to the residue of lime or wood ash during steaming/cooking process or due to the presence of calcium phytoliths in the paper. However, most of the *Pi* papers (#21,22,23) were slightly acidic, except paper from Hebei (#20).

2.3.5 Artificial Aging

In general, the color of the papers after aging appeared to be yellower than that of paper before aging. The paper samples from Zhejiang (#11, 12) appeared to be extremely brittle after aging.

2.4. Summary

The papers with the lowest strength, despite their high pH, appear to be those from Anhui (#1-10), and both these properties may be attributed to the present of phytoliths. Their strength was even lower than other *Hsuan (Xuan)* papers. In general, the physical strength of the modern handmade Chinese *Hsuan (Xuan)* papers is weaker than those of Chinese *Pi* papers, or Japanese papers. However, they might be suitable for conservation treatment of Chinese *Hsuan (Xuan)* paper artifacts for mending and filling, depending on the strength of such artifacts.

3. TREATMENT DEVELOPMENT FOR A CHINESE WOOD BLOCK PRINT

The Chinese wood block print described at the beginning of this article needed to be flattened and mended. This was a problem because the media was extremely water soluble and the paper was extremely deformed and brittle. In order to safely flatten and mend the print, several treatment techniques were developed, tested, and compared. A summary of the developments follows.

3.1. Flattening - Dry

Because the crumpled print was so brittle, it first had to be opened and initially flattened between two pieces of polyester film pressed with a small pointed softhair brush. Polyester films were used to absorb the stress imposed on the print, because of the fragility of the paper artifact. Once the print was uncrumpled, it became apparent that the piece was originally broken into two pieces.

3.2. Flattening - Humidity

3.2.1. Gore-Tex / Humidity Chamber

After dry flattening, the print had to be further flattened, using humidity, to realign the pieces completely. Because a yellow colorant in the media was extremely soluble in water, a mock-up procedure was designed to determine what humidity level and application method[xlv] was appropriate for the piece. It was found that 60% RH for 15 minutes caused no off-setting of media. A combination of Gore-Tex and humidity chamber humidification techniques was selected as an appropriate second phase flattening technique, to avoid any direct contact with the surface of the print.

3.2.2. Local Humidification

Because the paper was very thin, a system for controlling local humidification for the third phase of flattening was used to prevent the print from drying quickly during flattening. The local humidification set-up and technique consisted of several steps. First, the crumpled print was place under an elevated screen on which a damp blotter rested. Next, polyethylene sheeting was placed over the damp blotter and elevated screen to keep the print from drying out quickly, since it was so thin. To work on the print, the polyethylene was raised and the elevated screen moved sideway to expose a few inches of the print to be flattened. Once a small section was flattened, it was covered with a polyester web, blotter, plexiglass and light weight to dry. At this point, a new area was exposed and the process repeated.

3.3. Mending and Filling

Once the print was flattened, light-weight Tengujo tissue was used to secure the two large separated pieces, with wheat starch paste, applied on a light box before the second flattening was undertaken. Mending of all tears was done with light weight Tengujo and wheat starch paste. Selected Anhui *Hsuan (Xuan)* papers were toned with acrylic emulsion and used to fill in the losses.

3.4. Rehousing

Although the print was mended and filled, it was still too fragile to be handled. Additional protection was necessary for safe handling, and it was decided to insert the print into a wrapper mat using a non-adhesive attachment method. A paper cradle matting method[xlvi] was modified for matting, using polyester film instead of paper as a support and cradle. The print was placed on polyester film, and strips of three-mil polyester film were laid to overlap the prints edges. The edges of the strips covering the print had been previously given a soft, non-abrasive edge by heat welding to form a rounded edge where in contact with the print. Once the print was sandwiched between the polyester film support and the four polyester edge strips, the polyester pieces were spot welded to each other, just outside the edge of the print, using an ultrasonic welder. This allowed the print to be held by the polyester "cradle" and inserted into a wrapper mat by attaching the polyester cradle to the window mat using double sticky tape.

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NOTES:

LIST OF TABLES IN ORIGINAL PUBLISHED ARTICLE

LIST OF FIGURES IN THE ORIGINAL PUBLISHED ARTICLE

[i] 1.References on Japanese papers include:
Thomas Collings and Derek Milner, "The Identification of Oriental Paper-Making Fibers," *Paper Conservator*, vol.3, 1978.
Kitty Nicholson and Susan Page, "Machine Made Oriental Papers in Western Paper Conservation" the National Archives.
M. Inaba and R. Sugisita, "Permanence of Washi (Japanese paper)," the IIC Conservation of Far Eastern Art- Kyoto Congress, 1988. M. Inaba and R. Sugisita, "Permanence of Washi (Japanese paper) Part II," the Materials Issues in Art and Archaeology II, vol.185, 1990.
Books on Japanese paper include:
Tim Barrett, *Japanese papermaking: traditions, tools, and techniques* (New York: Weatherhill, 1983); Kiotusa Narita, *Life of Tsai Lung and Japanese Paper Making* (Tokyo: Qainihon Press, 1966); *Handbook on the art of Washi* (Tokyo: All Japan Handmade Washi Association, 1991).
In addition, the evaluation of quality of modern Japanese paper has been conducted in the Conservation office at the Library of Congress; the result has been used to select Japanese papers for conservation treatments although LC research has not been published.

Reference on Japanese wood block prints include:
Amy Newland and Chris Uhlenbeck *Ukiyo-e to Shin Hange: the Art of Japanese wood block prints* (New York: Mallard press 1990); Keiko Mizushima Keyes, "Japanese Print Conservation - An Overview", Conservation of Far Eastern Art (IIC Kyoto Congress, September 19 - 23, 1988); Pamela de Tristan, "The Conservation of Nine Sumi Drawings (c.1838) by Utagawa Kuniyoshi the Japanese Ukiyo-e artist", Conference Papers Manchester 1992, Institute of Paper Conservation.

[ii]2. English references on History of Chinese papermaking include:
Tsuen-Hsuin Hsien, *Science and Civilization in China*, ed. Joseph Needham, vol. 5, pt. I (Cambridge: Cambridge University Press, 1954); Tsuen-Hsuin Hsien, "Raw Materials for Old Papermaking in China", Journal of the American Oriental Society, 93.4 (1973); Sung Ying-Hsing, *Tien-Kung Kai-Wu: Chinese Technology in the Seventeenth Century,* (University Park and London: Pennsylvania State University Press, 1966); Hilary Mullock, "Xuan Paper", Paper Conservator, vol.19 (1995): 23-30.

[iii]3.In the late 1993, the Conservation Analytical Laboratory (CAL) received a colored Chinese wood block print for treatment. This print was donated by Lt. T.G. Fillette in 1891 to the Anthropology Department at the National Museum of Nature History, Smithsonian Institution. It was printed in three colors: yellow, blue and red, onto a piece of thin cream-color oriental paper. The title "Victory of General Liu's Army - newly issued print" was printed in the upper middle center area. Catalog numbers in black manuscript ink are written at the upper right corner. Name and Place of publisher or distributor was printed at the lower left area outside the image boarder. The printed date is unknown, but it depicts a scene theoretically from late 1860s.

[iv]4. Pan, Chi-Hsing (Pan Jinxing), "Shih-Chieh Shang Tsai-Tsao-Ti Chih-Wu Hsien-Wei Chih, " (The Earliest Paper in the World) *Wen-Wu*, vol. 11, (1961).

[v]5. James Rumford, "Out of the Moving Waves - Some Notes on Chinese Papermaking", Hand Papermaking (winter, 1989), 6.

[vi]6. Ibid., 6.

[vii]7. According to Sung Ying-Hsing's *Tien-Kung Kai-Wu*, Bamboo fibers take about 100 days for fermentation.

[viii]8. Rumford, "Out of the Moving Waves - Some Notes on Chinese Papermaking", 7.

[ix]9.Chi-Hsing Pan (Pan Jinxing), *Zhongguo Zaozhi Jishu Shigao* ("History of Chinese Papermaking Technology) (Beijing: Wenwu Press), 47-8.

[x]10. Rumford, "Out of the Moving Waves - Some Notes on Chinese Papermaking", 7.

[xi]11. Ibid., 7.

[xii]12. Ibid., 7.

[xiii]13. Ibid., 8.

[xiv]14. According to Mr. Hsien in his "Raw Materials for Old Papermaking in China", Hemp (*Cannabis sativa*, Moraceae family, known as ta-ma in China, originated in Northern India and Persia) was probably the earliest material used for papermaking from the Western Han dynasty (206 B.C.-8 A.D.), followed by paper mulberry (*Broussonetia papyferia*, Moraceae family, known as *kozo* in Japanese) from the Later Han (25-220 A.D.), rattan (*Calamus rotang*, limited distributed in early Chinese papers at the south-east region) from the Wei/Jin dynasty (265-317 A.D.), bamboo (Graminae family, southern part, mainly Fukien province), contains 20% starch which normally stains pulp) from the middle of the Tang (618-906 A.D.), and straw (rice straw, *Oryza sativa*, Graminae family) probably from before the Song dynasty (960-1280 A.D.). See Russell A. Parham and Hilkka M Kaustinen, *Papermaking Materials: An Atlas of Electron Micrographs* (Wisconsin: Graphic Communications Center, 1974) 7, 14-15.

[xv]15. James Rumford, "Out of the Moving Waves - Some Notes in Chinese Papermaking", 6.

[xvi]16. Mullock, "Xuan Paper", 28.

[xvii]17. For source of illustration, see Thomas Collings and Derek Milner, "The Identification of Oriental Paper-Making Fibers", Paper Conservator, vol.4 (1979), 16-7.

[xviii]18. For source of illustration, see Thomas Collings and Derek Milner, "The Identification of Oriental Paper-Making Fibers", Paper Conservator, vol.3 (1978) 70-1.

[xix]19. For source of illustration, see Thomas Collings and Derek Milner, "The Identification of Oriental Paper-Making Fibers", Paper Conservator, vol.3 (1978),78-9.

[xx]20. Tsien Tsuen-Hsuin, "Raw Materials for Old Papermaking in China", Journal of the American Oriental Society 93.4 (1973), 513.

[xxi]21. Hilary Mullock, "Xuan Paper", Paper Conservator, vol.19 (1995),23-30.

[xxii]22. Zao Zhi Shi Hua ("History of Chinese Papermaking") (Shanghai: Science and Technology Press, 1983), 57.

[xxiii]23. References on grass fibers are Elaine and Donna Koretsky, "Rice Straw Paper", Hand Papermaking (Summer, 1990); Zao Zhi Shi Hua (History of Chinese Papermaking), 62-4.

[xxiv]24. Reference on the use of bamboo fibers are: Hsien, " Zao Zhi Shi Hua ("History of Chinese Papermaking"), 60-1.

[xxv]25. *Zao Zhi Shi Hua* ("History of Chinese Papermaking"), 65.

[xxvi]26. Ibid., 64.

[xxvii]27. Ibid., 65.

[xxviii]28. Mixtures for blue sandalwood and straw will be discussed under the section 1.3 Chinese specialty papers.

[xxix]29. This paper is referred to in some articles, such as Mullock's, as Xuan, which is the mainland Chinese spelling. Hsuan is the Taiwanese spelling.

[xxx]30. Mulberry (Morus alba) *"sang"* is chiefly cultivated for the culture of silkworms. Its fiber was later used for papermaking by the people in the north. See Tsuen-Hsuin Tsien, *Science and Civilisation in China*, 59.

[xxxi]31. Studies of paper absorbency and wetting properties of Chinese ink on *Hsuan (Xuan)* papers include *Xuan Paper with Chinese Painting and Calligraphy*, compiled by Renqing Liu, (Beijing: Light Industry Press, 1989).

[xxxii]32. Hsien, "Raw Materials for Old Papermaking in China," 6.

[xxxiii]33. Liu Jen Chin (Liu Renquing), "Characterizing Chinese Hsuan (Xuan) Paper", *Pulp and Paper*. vol. 82.5 (1993): 6.

[xxxiv]34. Mullock, "Xuan Paper", 28.

[xxxv]35. *Zao Zhi Shi Hua* ("History of Chinese Papermaking"), 66.

[xxxvi]36. Mullock, "Xuan Paper", 28.

[xxxvii]37. *Chih De Da Kuan*, (Taipei: Ivy Leave Press, 1990), 40-5

[xxxviii]38. The HunterLab Ultrascan spectrometer was set on "RSIN (Reflectance - Specular Included) /UVL OFF (UV Lamp off)/UVF OUT (UV filter out) /LAV (Large area view)" mode.

[xxxix]39. Because selected samples were received at the different time and because of the quantity of samples, two groups of samples were aged separately.

[xl]40. Consultation with Dr. Bob Blanchette, a plant pathology professor at the University of Minnesota, led to the identification of the fibers as phytoliths. However, since preparation of this manuscript for publication, a new reference has been published: Marja-Sisko Ilvessalo-Pfaffli, *Fiber Atlas: Identification of Papermaking Fibers*, (New York: Springer), 1995.

[xli]41. Terry B. Ball, Jack D. Brotherson, and John S. Gardner, "A Typologic and Morphometric Study of Variation in Phytoliths from Einkorn Wheat," *Canadian Journal of Botany*, vol. 71 (1993): 1128.

[xlii]42. Lawrence Kaplan, Mary B. Smith, and Lesley Ann Sneddon, "Cereal Grain Phytoliths of Southwest Asia and Europe," in *Phytolith Systematics*, ed. George Rapp, Jr. and Susan C. (New York: Mulhollands, Plenum Press, 1992), 155-63.

[xliii]43. During the first experiment, the optimum clamping pressure was set on 15 psi for *Hsuan (Xuan)* paper samples (Table 2.1). However, it was unable to pull *Pi* paper

fibers apart. It also indicates that the strength of *Pi* fiber might be greater than that of *Hsuan (Xuan)*.

[xliv]44. Ti I Ching Kung Yeh Pu Tsao Chih, *Zhong-Guo Zao Zhi Yuen Liao Xien Wei Tu Pu*, (1965), 5,6,11,14.

[xlv]45. The Sovereign moisture meter, set on scale B, was used to control moisture. Two humidification methods (Gore-Tex/ humidity chamber and Gore-Tex/Gore-Tex) were set up in 60% and 80% humidity contents for 15 minutes, 30 minutes, 45 minutes and 60 minutes. 60% for 15 mins was selected and the combination of Gore-Tex and humidity chamber was selected as an appropriate humidity flattening to avoid any direct contact with surface of the print.

[xlvi]46. Hugh Phibbs, "Hinging Options" Picture Framing Magazine (July, 1993), 104-10.