Chapter 3
Papermaking: The Historical Diffusion of an Ancient Technique

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Paper was invented in China in the centuries before Christ and carried by Buddhist monks throughout East and Central Asia (Tsien, 1985), where Muslim Arabs encountered it in the eighth century CE. Muslims carried paper and papermaking to the Mediterranean region, and European Christians there learned how to make it by the twelfth century. Europeans not only forgot their debt to Muslim papermakers but also remained ignorant of paper's origins in China, so that when they first encountered Chinese paper in the sixteenth century, they thought that the Chinese must have learned the art of papermaking from the ancient Egyptians! Europeans then carried paper and papermaking, along with printing, throughout the globe. While the history of paper has traditionally been overshadowed by the history of printing, the spread of paper and papermaking is arguably equally important, for this relatively permanent, cheap, and flexible material not only encouraged the spread of written culture across the globe but also transformed many other human activities.

This paper studies mobilities of knowledge from the perspective of paper making by examining how and when this technique diffused from China across Eurasia to the Mediterranean region and from there to the rest of Europe in the period between 600 and 1500. The main factors that enhanced and impeded this spatial diffusion of knowledge were the availability of raw materials and the adoption of differing technologies, but the roles of mediating aspects such as religion, trade, emigration, imports, and exports will also be discussed.

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H. Jöns et al. (eds.), *Mobilities of Knowledge*, Knowledge and Space 10,
DOI 10.1007/978-3-319-44654-7_3

The Early Diffusion of Papermaking

Paper is a mat of cellulose fibers that have been beaten in the presence of water, collected on a screen, and dried. The manufacture of paper requires only cellulose, which can be extracted from various types of plants or textile waste, and fresh water for processing the fibers, as well as a screen on which to collect them. In principle paper can be made virtually anywhere, and the relative simplicity of the technique allowed cultures and individuals wide variation in the actual materials and specific processes used to make paper, depending on what was locally available and what was known. That said, making good paper is an art. Warmer and drier conditions are preferable for papermaking, as the fibers must be beaten wet, the papermaker has to put his hands in the vat, and the water has to drip and evaporate from the formed sheets, but paper can be made successfully even in often cold and damp climates, such as Holland, where it began to be made in the late sixteenth century.

In the warm and humid regions of China where paper was invented, papermakers made their product principally from bast fibers collected directly from semi-tropical plants and shrubs, but it could equally be made from the cellulose in linen and cotton rags, old ropes, and other textile waste, a process that was adopted in the harsher and drier climates of Central Asia (Hoernle, 1903), where it was used not only by the Buddhists who had introduced paper to the region but also by local merchants and bureaucrats. After Muslims conquered Central Asia in the late seventh century, their burgeoning bureaucracy quickly began to use paper for record-keeping because it was relatively cheap, plentiful, and writing on it could not be erased without detection.

The Replacement of Papyrus and Parchment

By the late eighth century paper was being manufactured in Baghdad, the capital of the Abbasid caliphate in central Iraq, and its use and manufacture was soon disseminated throughout the empire. Paper was introduced to Syria ca. 800, and it quickly spread throughout the Arab Mediterranean lands replacing papyrus and parchment, the two portable and flexible writing supports that had been used in the region for millennia.

Papyrus was made from the stalks of a reed that grew primarily along the banks of the Nile River in Egypt. The fresh stalks were cut into lengths, sliced into strips, laid in two overlapping layers at right angles to each other, pressed together, and dried. Individual sheets could be glued together to form rolls and scrolls, the form in which papyrus was normally used. Papyrus rolls had been made from ca. 3000 BCE and exported from Egypt to Greece and other Mediterranean lands. While the papyrus reed could grow in other warm riparian environments, only in Egypt did the plant grow thick enough to make the production of writing materials practical, so its production remained an Egyptian monopoly for about four millennia.

The other flexible writing support used in antiquity was parchment, from the Latin *pergamena*, referring to the city of Pergamon in western Anatolia. It is a taut, stiff and relatively inelastic material made from skins, primarily from sheep and goats, that have been soaked in water and lime, scraped of their hair and fat, and dried under tension. The Roman author Pliny claimed that parchment had been invented in the second century BCE when Eumenes II Soter, ruler of Pergamon, had to invent a new writing material because the Ptolemies of Egypt, jealous of Pergamon's growing library, had embargoed shipments of papyrus. Other Classical sources, however, indicate that parchment and leather had been the principal writing media in the lands east of the Mediterranean. The Jews, of course, have since ancient times used parchment rolls for copies of the Torah, and parchment is known to have been used in western Central Asia in early Islamic times (Khan, 2007). The eastward spread of this material was limited, however, by the westward spread of Buddhism, which abhorred using the skins of dead animals for writing.

The Romans initially regarded parchment as inferior to papyrus, a writing material sanctioned by some 3000 years of use throughout the Mediterranean basin, and they deemed it suitable only for use in notebooks, not rolls. Although parchment was much more expensive than papyrus—primarily because the animal had to be killed to make a sheet—it did have the great advantage that it could be made anywhere if appropriate animals were available, or effectively everywhere. It also did not fray or split when folded, a distinct advantage as the codex form of book, previously used only for wooden tablets coated with wax and used for temporary note-taking, became more popular with the coming of Christianity (Roberts & Skeat, 1983). Parchment also survived better in a wider range of climatic conditions, particularly humidity, although direct contact with water would cause a parchment sheet to cockle and be irreparably damaged.

Medieval European and Byzantine chanceries continued to use papyrus for as long as it remained available. The great Belgian historian Henri Pirenne (1954/2001) thought that papyrus disappeared from Gaul as a result of the Arab conquests of North Africa, which supposedly interrupted Mediterranean trade (pp. 169–170), but the papal chancery in Rome continued to use papyrus until the eleventh century (McCormick, 2001, pp. 704–708), indicating that the trade in papyrus continued despite the Arab conquests. By the middle of the ninth century, however, the papal writing office began stockpiling supplies, because Egyptians began to produce more paper than papyrus. Archaeology confirms the shift from writing on papyrus to paper in the Islamic lands, and by the thirteenth century a traveler to Egypt explicitly declared that the manufacture of papyrus was quite forgotten.

Cultural Geographies of Papermaking

The widespread availability of paper encouraged an extraordinary culture of book-learning throughout the Muslim lands that was unparalleled in contemporary Christendom, which continued to rely on relatively expensive parchment, thereby restricting the number of writers and readers (Bloom, 2001). Nevertheless, cultural

factors affected the diffusion of its manufacture over space and time. For example, Chinese Buddhist monks and missionaries carried paper and papermaking at an early date to Korea, Japan, and Vietnam, and they must also have simultaneously brought that knowledge to India, for they went there to collect and copy original Buddhist texts. Yet paper does not seem to have been used or manufactured in India until well after the region was conquered by Muslims in the late twelfth century, presumably because Indian writers were perfectly happy with using palm leaves, the traditional support for writing on the subcontinent (Soteriou, 1999) (Fig. 3.1).

Similarly, the Byzantines surely knew of paper by the ninth century, for Christians in Damascus were using paper as soon as Muslims (Perria, 1983–1984), but they did not really start using it in earnest until centuries later (Oikonomidès, 1977). They must have felt that parchment was more durable than paper, for a document written in 1118 states that the original copy of a convent's charter was to be preserved on parchment in the church of Hagia Sophia, while paper copies were to be kept in the convent itself. From the late twelfth century, however, paper manuscripts became increasingly common in Byzantium, although there is little evidence that paper was ever made there before the Ottomans took the city in 1453 (Kâgitçi, 1963, p. 37). Finally, Muslim merchants from North Africa crossed the Sahara to West Africa, introducing Islam to the region by the year 1000. As elsewhere, Muslims surely introduced books and book learning along with their religion, but despite the abundance of the necessary materials no paper was made in the region until the twentieth century, suggesting that the nature of the Muslim community in the region was fundamentally different from that found elsewhere (Bloom, 2008).

Spatial Adaptations in the Technology of Papermaking

The transformation of raw plants or textile waste into a pulp of cellulose fibers suitable for papermaking requires not only the raw materials but also a considerable amount of physical effort and time. The fibers are first washed to clean them and then soaked, fermented, and/or cooked to soften them; they are then beaten in water until they break down into a uniform pulp (*stuff*) that can be suspended in water for the actual formation of the sheet. Papermaking therefore requires an adequate and steady supply of pure water for manufacture. As the only way of bleaching fibers before the discovery of chlorine in the eighteenth century was to expose them to the sun, the preparation of white paper required either clean white fibers or a sunny climate. Many early Arab papers are decidedly tan or even brown.

Zhi, the Chinese word for paper, was defined in a Chinese dictionary compiled around the first century CE as "a mat of refuse fibers." The Chinese character for *zhi* [紙] bears the silk radical at its left and the right part indicates the pronunciation. Since such processes as the treatment of refuse silk, the reuse of old fibers in quilted clothes, and the washing of hemp and linen rags are attested in China as early as the sixth or fifth century BCE, it is possible that someone accidentally left wet refuse fibers on a mat and let them dry, from which somebody got the idea of deliberately

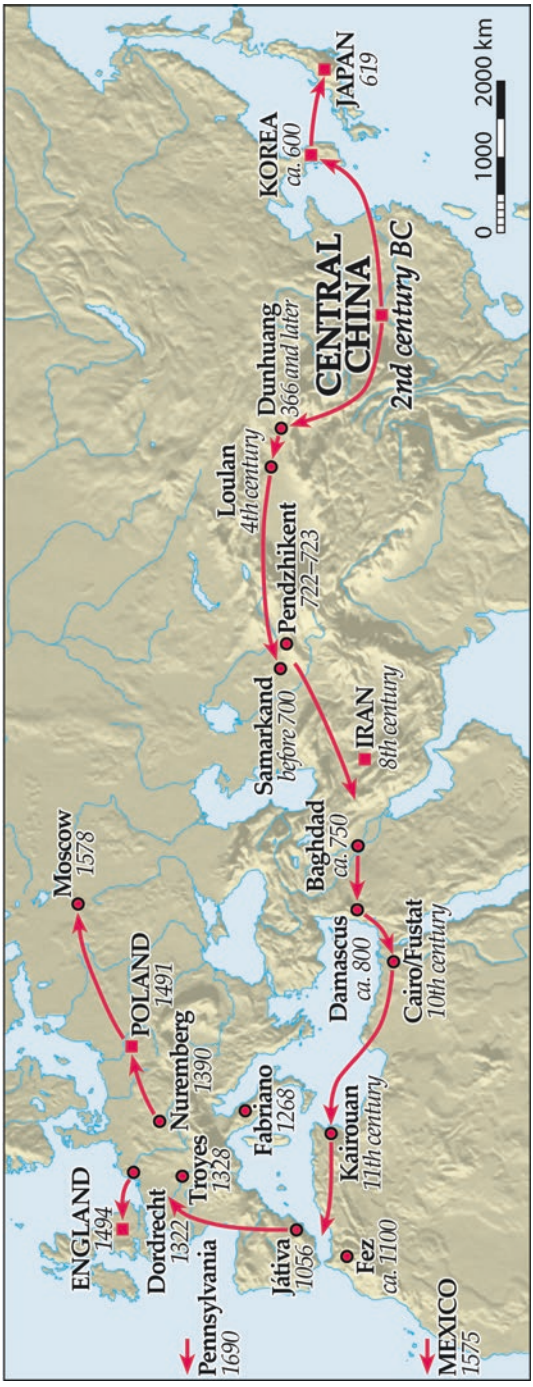

Fig. 3.1 The diffusion of paper making across Eurasia (Design by author; cartography by V. Schniepp)

forming them into a thin sheet. As silk fibers, however, have neither the physical nor chemical properties of cellulose that are essential to papermaking, true paper could not have been made from silk refuse.

Paper Mills

After the fibers had been collected, sorted, washed, and fermented, the physical breakdown of the cellulose fibers into a pulp was initially accomplished using a heavy wooden pestle in a stone mortar. From an early date, however, this time-consuming and arduous process was mechanized, whether by using human-powered trip mills, water-powered hammer mills, or perhaps animal-powered edge mills, particularly as papermakers made increasing quantities of paper. Pulp for paper was normally produced by pounding the raw material rather than grinding it between stones, although some authors have speculated that Muslim papermakers reduced rags to pulp by grinding them in an edge mill, in which the edge of a circular millstone rolls around a central pivot in a stone trough. An edge mill, however, would not have allowed the papermaker to sufficiently control the beating process upon which the quality of the finished paper depended. The cellulose fibers had to be broken down sufficiently to become hydrated, meaning that the outer layers of the fibers partially detach as microfibrils, causing water molecules to attach themselves to the exposed hydrogen atoms of the cellulose microfibrils. As the paper sheet is formed, the cellulose fibers combine physically and chemically to give the material its characteristic strength (Bloom, 2001, pp. 3–4).

Pounding mills could, in principle, be powered by human energy (a man could lift the pestle with his arms or step on and off a pivoted beam attached to the end of a pestle), but in practice they were usually powered by water. The Chinese had used water power for industrial purposes by the first century CE and used vertical undershot wheels to pound raw materials as early as the third century, whether as stamp mills (in which a rotating axle lifts cams) or hammer mills (in which cams depress the pivoted lever-arms of trip hammers). This type of mill was used in China to husk rice and is attested in Western Europe in the Middle Ages before ca. 1000, where it was used to full, or felt, woolen cloth. Such mills are also attested in eleventh-century Iran, where they were used to crush ores and flax for paper (Hill, 1993, p. 112), suggesting that the technology diffused across Eurasia.

Water-powered mills with both horizontal and vertical wheels had been used throughout the Roman Empire, and these technologies were not lost with the coming of Islam (Lucas, 2006; Wilson, 1995). As by the tenth century Islam also carried the cultivation of rice, as well as the need to husk it, from Iraq, where it had been cultivated in pre-Islamic times, to the Iberian peninsula, it seems logical to conclude that the milling technology traveled with the cultivation of rice (*The Encyclopaedia of*

Islam, 1960–, s.v. "Ruzz" by D. Waines). Although there is no hard evidence that the water-powered paper mills that are noted in twelfth-century Spain were of Islamic origin, there is no reason to believe that they were not (Hill, 1993, p. 113). This varied evidence suggests, therefore, that water-powered hammer mills spread around the Mediterranean along with Islam and the manufacture of paper, if not also the cultivation of rice. The need for waterpower to power mills also explains why paper mills in the Islamic lands were invariably found alongside rivers and streams, not just lakes and ponds that could provide fresh water for papermaking itself. For example, from the ninth-century geographers note the existence of paper mills outside the walls of Damascus on a branch of the Barada river. Other paper mills existed in the cities of Hama and Tripoli, but there were none at Aleppo because no stream was strong enough to power the mills (Elisséeff, 1967, pp. 868–869). An Andalusian geographer who visited Egypt in the 1240s remarked that paper mills were confined to Fustat along the Nile and not found in Cairo itself, which was built on higher—and drier—ground (Al-Maqrizī, 1853, p. 1:366; Goitein, 1967–1994, p. 1:81 & fn. 2).

Although the great rivers of the Islamic heartlands such as the Nile, the Tigris, and the Euphrates were able to provide sufficient waterpower for milling, they flow relatively slowly, carrying water from distant mountains across great expanses of relatively flat and arid land. Elsewhere in the region, smaller rivers and streams might flow only intermittently after seasonal rains. In contrast, European rivers and streams, although smaller, flowed faster and stronger over more rugged terrain. Europeans were able to harness the greater and more constant potential energy in their waterpower more efficiently than Near Easterners and North Africans, principally because they used overshot (rather than undershot) water-wheels to power their mills and they were also technological innovators. Italian papermakers arranged their stampers in batteries, so that the rags were transformed into a finely and evenly beaten pulp by passing successively from one stamper to another, and they furnished the ends of their stampers with spikes to reduce rags to pulp more efficiently (Barrett, 2012).

In the Netherlands the absence of the fast-flowing streams characteristic of other papermaking centers led to the invention of the Hollander beater in the seventeenth century. Powered by wind, the Hollander beater reduced rags to fibers by beating them between a ridged cylinder and a bedplate set within an oval tub or tank. The rags circulated continuously through the beater, reducing to a pulp in a mere fraction of the time it would have taken in a stamper mill (Bloom, 2001, pp. 217–218). Although a Hollander beater could be used carefully to produce a paper equal in quality to that produced by stampers, in the hands of an incompetent papermaker it was much easier to spoil an otherwise good fiber by overbeating. Because of its efficiency, the machine was widely adopted, although it did not entirely replace stampers. Its introduction accompanied a tremendous upsurge in demand for paper and the results were not always of the highest quality (Barrett, 2012).

Raw Material Used for Papermaking

Although the Chinese character for paper suggests that its discovery was related to textile waste, for centuries the Chinese had used bast fibers extracted from such semi-tropical plants as paper-mulberry (*Brousonnetia papyrifer*), hemp, jute, rattan, and bamboo for papermaking, and papermakers in East Asia followed suit. For example Japanese papermakers typically used kozo, mitsumata, gampi, and other plants that provided long fibers, which when seen under a microscope resemble "buttered spaghetti" (Barrett, 1983/1992, p. 21.) and give the paper its characteristic strength and feel. Such plants did not grow in the arid climate of Central Asia, however, and papermakers there apparently discovered (or rediscovered) not only that paper could be made from rags and waste from textiles made from such plants as cotton, flax, and hemp, but that it was easier to make paper out of fibers that had already been processed and bleached in the sun. Muslim Arab papermakers consequently learned to make paper from both bast fibers and rags.

Cotton, whose fibers are almost pure cellulose, was much less commonly grown in medieval Islamic times than was linen or hemp, as it flourished in only a few regions, including Central Asia, Iran, Palestine, and Yemen (Amar, 2002; Bulliet, 2009; Lamm, 1937). Cotton therefore played a relatively insignificant role in papermaking until the eighteenth century, when great quantities of Indian cottons were imported into Europe and cotton rags made into paper. Egypt, for example, only began to grow cotton in the nineteenth century when the American Civil War disrupted supplies to British mills. But the myth of cotton paper has persisted because Byzantine sources termed Arab paper *bambuxinon*, *bombuxinon*, and *bambaxeron*, and sometimes in late texts as *Bambaxeros kartis*. Nineteenth-century scholars thought the terms referred to *bombax* (which can mean *cotton* or *silk* in Greek), and supposed that these *bombycin* papers had been made from cotton or silk fibers. The term *bambuxinon* in fact refers to the Syrian city of Manbij (known in Greek as Bambyke), located northwest of Raqqa on the Sajur river, whose abundant supply of water encouraged the manufacture of paper there at least from the tenth century (*The Encyclopaedia of Islam*, 1960-, s.v. "Manbidj" by N. Eliséeff).

One of the few medieval accounts of Arab papermaking anywhere survives in the treatise on making books by the Zirid prince al-Mu'izz ibn Badis (r. 1016–1062) (Levey, 1962, pp. 39–40). Ibn Badis's text, however, is remarkably inaccurate, for he says paper is made only from *qinnab* (or *qunnab*, hemp, although Levey curiously translates it as "white flax" or *hibiscus cannabinus*, a shrub known in English as kenaf) that is prepared by soaking in quicklime and water. Ibn Badis neglects to mention the use of rags, which we know papermakers actually used, and he describes a one-piece floating mold that most papermakers had long abandoned. A thirteenth-century Yemeni recipe for making *local* paper (*al-kaghād al-baladī*) also ignores rags and states that it was made from the white fibers of the inner bark (*liḥā'*) of the fig tree (*mudakh*). The outer layers are peeled off and discarded, the remaining fibers soaked for several days in fresh water, fermented, dried in the sun, soaked, cleaned, pounded, dried, soaked again, drained and squeezed into balls. The moist

balls are then beaten for 5 days with a mallet until they are like wheat dough, then the mass is sprinkled with water and kneaded before being mixed in a vat of water for the actual papermaking. A one-piece mold is dipped in the vat and the sheets are released immediately after they are made (Gacek, 2002). In short, it would appear that papermakers in the Islamic lands were ready to use a wide variety of fibers and techniques to prepare them.

Microscopic examination of medieval Arab papers occasionally reveals unprocessed threads and bits of cloth indicating that the pulp was made with rags, although other bits of unprocessed plant stalk may show that bast fibers were used as well. Archaeologists' discoveries of piles of rags in the ruins of Fustat (Old Cairo) may have been left by ragmen who had collected them for papermakers to recycle. The 1980 excavations at Fustat, for example, yielded approximately 3000 textile fragments, most found in refuse heaps from the eleventh century. Roughly 70 % of the textiles found were relatively coarse undyed linen; about 12 % were linen dyed blue with indigo and 8 % were heavy fabrics woven with undyed linen, possibly hemp or reed. Another 5 % were blue-and-white striped, checked, or plaid linens. The remaining 5 % included textiles of wool, silk, cotton, hemp, and reed (Kubiak & Scanlon, 1989). While this mix may represent the ratio of fibers used by the population at large, virtually all but the wool and silk—and the percentage of them was so small it would hardly have mattered—would have been appropriate raw material for Fustat's paper mills.

Egyptian papermaking depended on a ready supply of linen rags, and Egypt had produced great quantities of flax from ancient times, but at the beginning of the fifteenth century, Egyptian habits of dress changed. The Egyptian textile industry went into a serious decline, largely as a result of depopulation after the Black Death, technological stagnation, and the mismanagement of the economy by the ruling Mamluk elite. Native Egyptian linen became increasingly expensive and for the first time upper-class Muslims began to wear garments made from European woolen broadcloth, rather than from domestic linen (Mayerson, 1997). The increased availability of European woolens and declining Egyptian production of linen meant that fewer raw materials were available for Egyptian papermakers, and Italian papermakers were more than happy to flood the market, particularly since increased quantities of linen (and consequently rags) had become available in Europe due to several late-medieval technical innovations including the flax-breaker and the spinning-wheel (Bloom, 2001, p. 83; Strayer, 1982–1989, s.v. "Linen").

In addition to the evidence of the paper itself, texts tell us that rags were used in the Iberian Peninsula for papermaking by the twelfth century. Peter the Venerable (d. 1156), abbot of the French monastery at Cluny, complained about Spanish monks using a material made from "scraps of old rags, or, perhaps, from even viler stuff" (Valls i Subirà, 1970, pp. 5–6). The catalogue of the Silos monastery library in the thirteenth century refers to a Toledan missal on "rag parchment [*pergamino de trapos*]," presumably because the author did not think his readers would understand a specific word for paper. By 1274 the manufacture of paper in Valencia, which was known for its cultivation of flax (and rice), had become so important that King James (Jaume) I of Aragon (reigned 1213–1276) prohibited the sale of rags to

merchants from Perpignan, suggesting that the French were already making paper as well. In 1306 an embargo was placed on exports to France including paper (Valls i Subirà, 1970, p. 16). English paper production, which had begun fitfully two centuries later around 1500, ceased temporarily in the early 1640s during the Civil War because of a decline in linen production. To encourage the use of wool and save linen and cotton for papermakers, the English Parliament decreed in 1666 that the dead could be buried only in woolen clothing or shrouds (Hunter, 1943/1957, p. 482).

Paper was also recycled into other products, including paper. Pages from discarded books, such as the *Thousand Nights* fragment in Chicago, were used as scratch paper, and many of the other scraps found in the Fustat dumps were repeatedly reinscribed. Even after paper began to be manufactured in Egypt, it was still saved for reuse and recycling (Goitein, 1967–1994, p. 1:7, 334). Old paper might be used for stuffing and stiffening garments such as caps, and sheets of old paper (and parchment and papyrus) were pasted together to make pasteboard for book bindings. Several texts of the thirteenth and fourteenth centuries insist that papermakers be careful to keep their paper pure by not recycling papers on which sacred texts or names were written (Le Léannec-Bavavéas, 1998, p. 75), a concern that may serve to explain the initial hesitation for using paper for copying the Koran.

Molds and Papermarks

From whatever it was made, the beaten and hydrated pulp was collected in a shallow mold consisting of a wooden framework on which a screen rested or was strung. In the Far East, molds are typically made of wood with a loose screen made of very thin splints of bamboo that have been laid parallel and bound together with silk thread (Barrett, 1983/1992, p. 78), but in the Islamic lands where bamboo was not available the screen appears to have been made from materials such as plant fibers stiffened with oil and horsehair. No matter what they are made from, these parallel supports leave faint series of “laid lines” on the finished sheet, often complemented by faint “chain lines” where the supports have been joined by threads or hairs. No medieval molds have survived in the Islamic lands, but the wavy laid lines sometimes visible on medieval papers indicate that the screens were made from organic materials that had sagged rather than from brass wire, which became the norm for the stronger molds eventually developed in Europe. From the thirteenth century, artisans in Germany, especially Nuremberg, perfected the art of drawing brass wire through increasingly narrow dies, allowing the creation of a mold that was less liable to warp or sag from repeated immersion in the vat (Bloom, 2001, p. 208).

The oldest type of mold, a simple rectangular frame with an integral screen, often of cloth, is still used for simple papermaking. The mold can be floated in a shallow pool of water and the liquid pulp is poured into the mold. The mold is then lifted, drained, and set to dry, after which the sheet is released from the screen. The same mold can also be dipped into a vat of pulp, lifted, shaken, and drained. The

advantage of this simple mold is that, as the *stuff* is not suspended in a large tank, it requires less pulp and water to make the sheet, and the water supply is not polluted with the excess pulp. The disadvantage is that a separate mold is required until each sheet dries and the two sides of the resulting paper differ in texture, making it inappropriate when one wants to write on both surfaces.

The two-piece mold, with a separate deckle (frame) and screen, however, allowed faster production of more even sheets because the just-formed sheet could be released from the screen, stacked with other sheets, and the mold reused immediately. This more efficient technique was used with variations throughout Eurasia, although a floating mold might occasionally be used for special production, particularly of enormous sheets for special purposes (Blair & Bloom, 2006).

All papermakers know that the screen leaves impressions on the finished paper, and even a few drops of water dripped on the sheet after it is formed can leave unwanted blemishes ("papermaker's tears") on the finished paper. Spanish papermakers had already used this knowledge to put zig-zags, a series of diagonal marks, onto on the sheet when it was still damp. They are the most distinctive feature of Iberian paper before the mid-fourteenth century, but their purpose is unclear: they may have been a precursor of watermarks or an indication of the paper's grain; the traditional explanation is that they were intended to imitate the tanners' marks that are sometimes seen on parchment (Le Léannec-Bavavéas, 1998, p. 71; Valls i Subirà, 1970, pp. 8–9) but more recent research suggests that they were introduced to slightly thin the sheet where it was to be folded when making a book so that the swelling of the spine would be reduced (Estève, 2001).

The introduction of molds made from brass wire made possible the introduction of watermarks, the most significant invention of Italian papermakers at Fabriano, a town in the Marche of Ancona where paper was made from the middle of the thirteenth century. Although Arab papermakers as early as the tenth century had used trademarks pasted to their bundles (Arab. *rizma*, the origin of the English word *ream*) (Goitein, 1967–1994, p. 1:81), the earliest example of a Fabriano watermark dates from 1282. Watermarks, more properly called *papermarks* since they have little to do with water, are made by bending a design in brass wire and attaching it to the mold, so that it leaves a faint impression on the finished sheet. These designs indicated who had made the paper and thereby served as signs of quality. Fabriano paper was whiter and finer than its competitors, the result of a well-beaten high quality pulp; its thinner and more closely spaced laid lines were the product of a better mold (Irigoin, 1968).

The earliest watermarks were simple designs, as the relatively coarse wire would not allow much twisting into fancy shapes, but as finer wires became available the designs got more intricate. Although few if any early watermarks were dated, the careful correlation of specific watermarks and dated documents written on watermarked paper has allowed scholars since the nineteenth century to date the watermarks and consequently assign *post quem* dates to undated documents written on watermarked papers as well as to determine where particular stocks of paper originated (Briquet, 1907).

Further Processing of Paper

After formation, the wet sheet was placed or *couched* (pronounced *cooched*) in a stack and pressed to expel surplus water. European papermakers interleaved the sheets with woolen felts to keep them separate and absorb water during pressing, but there is no way of knowing when and where this practice was introduced. Japanese and Indian papermakers, for example, do not use felts but add a formation aid to the pulp to help keep the sheets separate after they are formed and pressed (Barrett, 1983/1992; Soteriou, 1999). As felt-making (a technique of textile fabrication not all that different from papermaking) was widely practiced throughout the Islamic lands from pre-Islamic times, it is possible that papermakers there also used felts and introduced the practice into Europe, although the subsequent coating of all Islamic papers with a size that was then heavily burnished has probably removed all evidence (such as stray hairs) of any felts that once might have been used.

After pressing the damp sheets are spread or hung out to dry. In warm climates the sheets can be spread on clean rocks or attached to smooth walls or boards; in cooler and damper northern climates, paper was spread on heated walls or hung on lines in special drying sheds (Barrett, 1983/1992; Harris & Wilcox, 2006). In East Asia papers were not sized and could be used at this stage, for the ink used for writing was applied with a soft brush and soaked into the paper. In the Islamic lands, however, writing was invariably done with a red pen (*qalam*), which would have caught on the rough surface of an unsized sheet of paper and the ink would have soaked in, so papers were invariably subjected to further treatment that consisted of coating with size and burnishing the surface.

Papermakers, stationers, or writers and artists in the Muslim world regularly sized their paper with starch, sometimes boiled with the addition of pure white chalk (Levey, 1962, p. 39) or of glue (Qāḍī Aḥmad, 1959, p. 114). The starch was often made from rice in the Mediterranean lands or from sorghum in Yemen (Gacek, 2002, p. 90). Wheat starch was difficult to extract and apparently had a disagreeable odor. Later Ottoman calligraphers sized their paper with a mixture of alum dissolved in egg white. The size was either brushed or daubed on; after it had dried, the sheet was burnished on both sides by placing it on a hard, smooth surface and rubbing it with a smooth stone or glass burnisher until the surface was perfectly smooth and even shiny.

In the presence of sufficient humidity starch supports the growth of molds and other microorganisms that eventually can destroy the paper itself, but this was not normally a problem in many of the hot and arid Islamic lands, although it did become a problem in cooler and more humid regions of Europe (Irigoin, 1960, p. 31). Gelatin, which Italian papermakers made from the hoofs, hides, and horns of animals, not only inhibited the growth of microorganisms on paper, but also gave the sheet a harder finish, more resistant to the quill pens which Europeans used to write on parchment. The first dated paper sized with gelatin is a document of 1264, although many paper mills still continued to size with starch after 1300 (Le Léannec-Bavavéas, 1998, p. 66). Recent research has shown that European papers made

before ca. 1500 were specifically made to imitate parchment, being generally thicker and with higher concentrations of gelatin and calcium than those made later, probably because earlier papers were primarily made to meet the needs of writers rather than printers (Barrett, 2012).

Trade Relations and the Decline of Arab Papermaking

The efficiency with which European papermakers made their product allowed them to dominate the market, not only in Italy but also throughout the Mediterranean, and led to the rapid decline of Arab papermaking. For example, as early as 1350, a letter from the sultan of Tunis to the king of Aragon-Catalonia bears a griffin watermark, indicating that the paper had been made in Italy (Valls i Subirà, 1970, p. 11). Another paper document from 10 years later bears both a watermark and a zigzag, suggesting that the Italian sheet had been made specifically for the North African or Catalan markets (p. 12).

A manuscript of the Koran was copied presumably at Baghdad on European watermarked paper as early as ca. 1340 (James, 1992, QUR 561), but European paper was not universally admired in the Arab lands. Some Muslims found watermarks to be offensive, particularly since the designs often contained a cross or an image of some living being. In Tlemcen, now in western Algeria, the noted jurisconsult Abu ʻAbdallah ibn Marzuq (d. 1439) delivered a long *fatwa*, or legal decision, on 21 August 1409 entitled "A Decision . . . concerning the permissibility of writing on paper made by Christians." According to the document, paper had once been made in Tlemcen as well as in Fez and in al-Andalus, but it was no longer. Pious Muslims were therefore forced to write on European paper with watermarks that they found offensive. According to Ibn Marzuq's decision, which saw the problem in terms of ritual purity, writing in Arabic rendered the idolatrous designs invisible. Writing God's name (and message) on such papers replaced falsehood with truth, much in the way Muslims used Christian churches as mosques (Halevi, 2008; Lagardère, 1995, p. 42).

Furthermore, Italian merchants mostly exported cheap paper to those Muslim countries that continued to produce paper; elsewhere, they also exported the better kinds. The once-vibrant Syrian papermaking industry seems to have collapsed as European papermakers began to export their own product to the Middle East in earnest. The Egyptian writer al-Qalqashandi (d. 1418) claimed that the European paper was "of the worst kind" (Ashtor, 1977, p. 270). Although Egyptians continued to manufacture some paper until the seventeenth century, from the sixteenth century French and Italian papers were dominant in Egypt. The few dated documents in the Cairo Geniza, a trove of medieval documents from the Jewish merchant community, from the second quarter of the sixteenth century, for example, are on European not local paper. By the sixteenth century, according to the historian Ibn Iyas, the paper market building was being used by textile merchants, a trenchant comment on the decline of the industry in the face of European competition

(Raymond, 1973–1974). By the eighteenth century Cairo had become only a redistribution point for the export of European paper to Arabia and Nubia (Bloom, 2008; Raymond, 1973–1974, p. 130; Walz, 1988).

Conclusion

In conclusion, the historical geography of paper and papermaking concerns far more than the mere history of a material and the technology to make it, for as it spread and was adopted by different societies in different regions, paper provided several *affordances* that encouraged a shift from oral to written culture and the development of various systems of notation, whether of language, mathematics, commercial transactions, music, or drawing and architectural drafting, quite apart from the invention and dissemination of printed books and images (Bloom, 2001; Bloom, forthcoming). In short, paper "started a new era of civilisation. The one we live in now" (Kremer, 1875–1877 as quoted by Karabacek, 1991, p. 72). An investigation of this subject, however, must be left for another study.

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