The Analysis of Paper and Ink in Early Maps

DAVID WOODWARD

WITHIN THE LAST TWENTY YEARS, several promising new means of analyzing the physical and chemical structure of historical artifacts have been introduced. So rapid have been the development and so wide the choice of available techniques that their comparative value has become unclear especially to practitioners in fields where analytical techniques have only recently been introduced. The aim of this article is to compare some of the opportunities available and to pose some questions concerning their value for the analysis of early maps.

The logical analysis of physical form in printed books and manuscripts without the use of electronic aids has a much longer, if sporadic, history. In analytical bibliography, for example, the study of the Thomas Wise forgeries by Carter and Pollard in 1934 was one of the earliest attempts at using detailed physical evidence of paper and typography to demonstrate conclusively the falsity of documents.[1] Their conclusions were elegant in their logic and simplicity and provided a methodological example of the value of careful and systematic physical observation, a viewpoint that had previously been neglected or even overlooked in favor of the document's content. In the history of cartography, this approach has already been summarized elsewhere by the author.[2] The recent addition of such techniques as beta radiography, external beam particle-induced X-ray emission (PIXE), and energy dispersive X-ray fluorescence (XRF) has provided new opportunities for the analysis of both manuscript and printed maps which the historian of cartography should consider.

David Woodward is Professor, Department of Geography, University of Wisconsin—Madison.

Opportunities

What are the physical components of a map that can be analyzed systematically? Simply expressed, they are the fabric (paper, vellum etc.) and medium (ink, paint, etc.).[3] Some techniques—such as beta radiography—are only applicable to paper analysis, while others—such as PIXE or XRF—may be applied to both the fabric and the medium.

Paper

The dating of paper used for maps starts in earnest with the work of Edward Heawood who combined a knowledge of paper history with the history of cartography and who used maps as examples for his volume in the series of watermark albums published by the Paper Publications Society.[4] Heawood's interest in this evidence is also seen in a series of articles on maps printed in Italy in the sixteenth century.[5] On account of the complicated plate histories of most of these maps with plates changing ownership several times during their lifespan, he demonstrated that the paper evidence could be especially valuable.

Heawood's interest in watermarks and in sixteenth-century Italian printed maps was continued by the scholar-collector George H. Beans, who between 1957 and 1962 presented most of his map collection to the John Carter Brown Library.[6] In addition to his collecting, Beans published his own and others' work in Jenkintown, Pennsylvania in a series of publications under the imprint of the George H. Beans Library including a small handlist of watermark tracings found on sixteenth-century Italian maps.[7] He also contributed to *Imago Mundi* on topics of his collecting interest under the title *Notes from the Tall Tree Library*.[8] Building on these studies of Heawood and Beans, since 1977 the present author has developed several lines of research on the dating of sixteenth-century Italian maps using several analytical methods.[9]

Comparative watermark analysis was severely hindered by the lack of an objective method of reproducing and recording the marks, a drawback that has now been largely solved by several imaging methods. The fastest and most economical of these is direct contact photography—known as the Ilkley method—in which high speed graphic arts film is laid under the map, glass laid on top of it, and the whole sandwich exposed to a 15-watt light bulb about eighteen inches away for approximately one second. Another method using ultraviolet radiation with special (Dylux) paper has the advantage that a darkroom is not needed. One drawback of both these methods is that the image includes the map detail, which often seriously obscures the watermark. For this reason beta radiography has gained increasing acceptance.[10] The hand tracing of watermarks—while suitable for general studies and certainly preferable to omitting the image altogether in a description—is now considered much less desirable than the objective methods.

In 1967, The Newberry Library in Chicago acquired part of the collection of Franco Novacco, which included approximately 330 sixteenth-century printed Italian maps. Between 1978 and 1980 the author acquired about 900 beta radiograph images of watermarks from these and other sixteenth-century Italian printed maps loaned to the library from other institutions and private collections. In addition, a set of watermark images was obtained from a sixteenth-century Italian atlas sold at Sotheby Parke-Bernet on 15 April 1980 to a private collection in England (its whereabouts are now unknown). Before the sale, the author cataloged a portion of the atlas in detail and photographed about 110 watermarks using the Ilkley process.

The atlas consists of a core of sixteenth-century maps inlaid in extended margins or marginal strips. The watermark evidence is crucial to establishing the date and place of assemblage which was concluded to be Venice ca. 1570. The key marks, illustrated in figure 1, are the siren-in-circle and horse-in-circle which are found respectively on the two sheets of the map of the world on a cordiform projection by Giovanni Paolo Cimerlino engraved in 1566. The siren watermark can be confidently identified as of Venetian origin, and its association with the horse mark on the Cimerlino map would suggest that the horse is also Venetian. This is the only map in the atlas in which the horse mark appears, but it occurs in the marginal strips with great frequency. One can therefore assume that the core of the atlas was assembled with the extended margins in a Venetian shop, probably in 1570, the date of the last map that has such margins.[11]

Further research projects at the University of Wisconsin have focused on all watermarks of one design from the entire collection of images—a siren (or mermaid with two tails) in a circle surmounted by a star. Forty-eight watermarks representing thirty-seven maps were selected (some maps consisted of two or more sheets pasted together). Sixteen images were obtained from The Newberry Library, Chicago; seven from Helsinki University Library; one from California State University, Fullerton; and twenty-four from private collections in California and London. Forty-three of the images were beta radiographs; the remaining were negatives made with the Ilkley process.

These forty-eight images were compared visually and found to fall into two distinct groups characterized by a difference in the shape of the

Figure 1a

Figure 1b

mermaid's right shoulder. In the Martha-type watermark, the right shoulder was broader than the left. The other image was called Mary. Out of 1000 images taken randomly from several collections worldwide, only *two* paper moulds of this design were represented. This surprising find indicated the likelihood that these two watermarks were from twin moulds and therefore most probably were always used in tandem in the papermaking process. This of course is not unusual in the making of handmade paper, but it does suggest that no other moulds bearing this emblem were used to make paper on which maps were printed, which was not expected.

Furthermore, five out of six sets of watermarks on the two-sheet maps turned out to be from the paired moulds, suggesting that, in a two-sheet map, there was a strong likelihood of printing the sheets one after the other rather than running off several copies of one sheet and then several copies of the other. This conclusion results from the likelihood that the sheets in a batch of paper (with inevitable exceptions) would normally remain approximately in the order that they were made, which would follow an alternating pattern using the two different moulds in tandem.

For the maps bearing an engraved date, the range of the plates was 1559-1570. The frequency of the dating is shown in figure 2, and it can be seen that the frequency increases toward the latter part of the period. None was found dated after 1570. Beans gave a range of 1561-1570 but also found none after 1570.[12] Something happened to this pair of moulds in 1570, and the search is on for maps with such a mark bearing a publication date of 1571 or after. However, on the basis of the large sample already gathered, it is unlikely that such maps will be found. Although a small sample is illustrated in figure 2, it is possible to infer that the marks were current during the latter part of the period only (that is, from 1566 to 1570), and that earlier dated maps were simply printed from the earlier plates during those years.

The question arises: How do we know if the difference between two watermarks is due to two states of the same mould or two different moulds? Fortunately, a technical detail in the manufacture of the mould comes to our aid. The watermark was usually attached to the mould with thin sewing wires which show up as light dots on the radiograph. Even if the shape of the mark should become distorted with use, therefore, the two patterns of the sewing dots will remain the same (see fig. 3). On the other hand, the likelihood of two marks on different paper moulds having the same pattern of sewing dots is slim indeed. In some cases, it is true, a sewing dot might be *added* to secure the watermark on

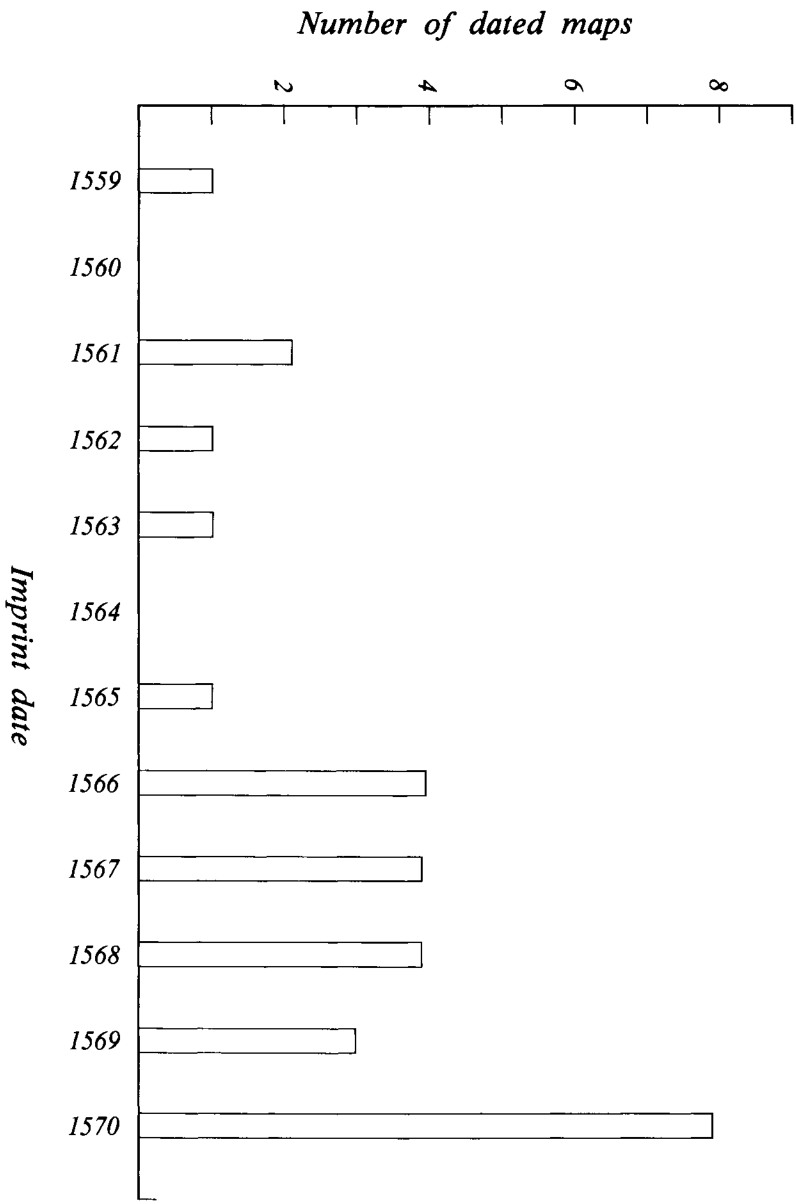
Number of dated maps
2
4
6
8
Imprint date
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570

Figure 2

the mould, but this can usually be identified and thus will aid and not hinder the ordering of the states of the mould.

A confident identification of the paper moulds in this experiment could not have been made before the techniques of watermark photography and radiography had been developed. But the possibilities for analysis do not end with mere identification. Stevenson has shown that paper moulds may go through identifiable stages during their existence analogous to the states of a printing plate. The mark may become increasingly distorted with use as the mould is jostled or as excess pulp is brushed from it. More dramatically, if the mark is situated between chain lines and not sewn to a chain line passing through it, the sewing wires tend to become loose with age and the mark moves slowly to the left in relation to the chain lines (see fig. 4). Stevenson even estimated the rate of movement as averaging about a millimeter a month, a distance certainly discernible on a radiograph.[13]

This theory is promising, but there are practical difficulties. The sewing dots are not always perfectly distinguishable even on the radiograph. Further, since each image had to be compared with every other image in this analysis to discern minute differences, the number of combinations exceeds 900. With this in mind, it was decided to take thirty-nine of the forty-eight images (those already in film form) to the University of Wisconsin's Center for Remote Sensing which recently acquired equipment for the analysis of satellite imagery, particularly Landsat.[14] These images were converted to numerical form on a scanning microdensitometer which records the film density of the radiograph at each of 350,000 small squares, here shown at normal size and enlarged eight times (see figs. 5 and 6). For each square or picture element three pieces of information were stored on tape or disk—the *x* and *y* coordinates of the picture element and the recorded density.[15]

Once the images are in digital form, they can be manipulated statistically in several ways. The range of density can be standardized from image to image by stretching the contrast between a given low and high figure. Further, the contrast of the images may be enhanced to bring out the pattern of sewing dots. If two images of watermarks from the same mould are superimposed on an image processor, these dots will become more prominent. If they are from different moulds, this will also become immediately apparent.

The analysis of successive states of a watermark using beta radiography can most easily be achieved when the mark is not wired to a central chain line (thus allowing it to slide along the wire lines during its lifetime). This was the basis of Stevenson's study. But for watermarks

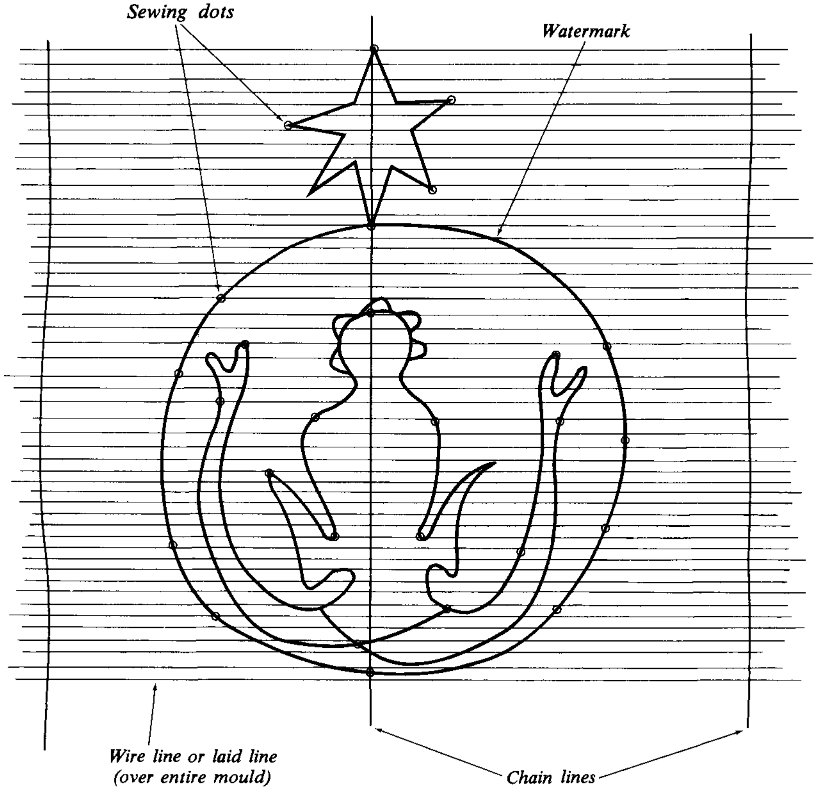
Sewing dots
Watermark
Wire line or laid line
(over entire mould)
Chain lines

Figure 3

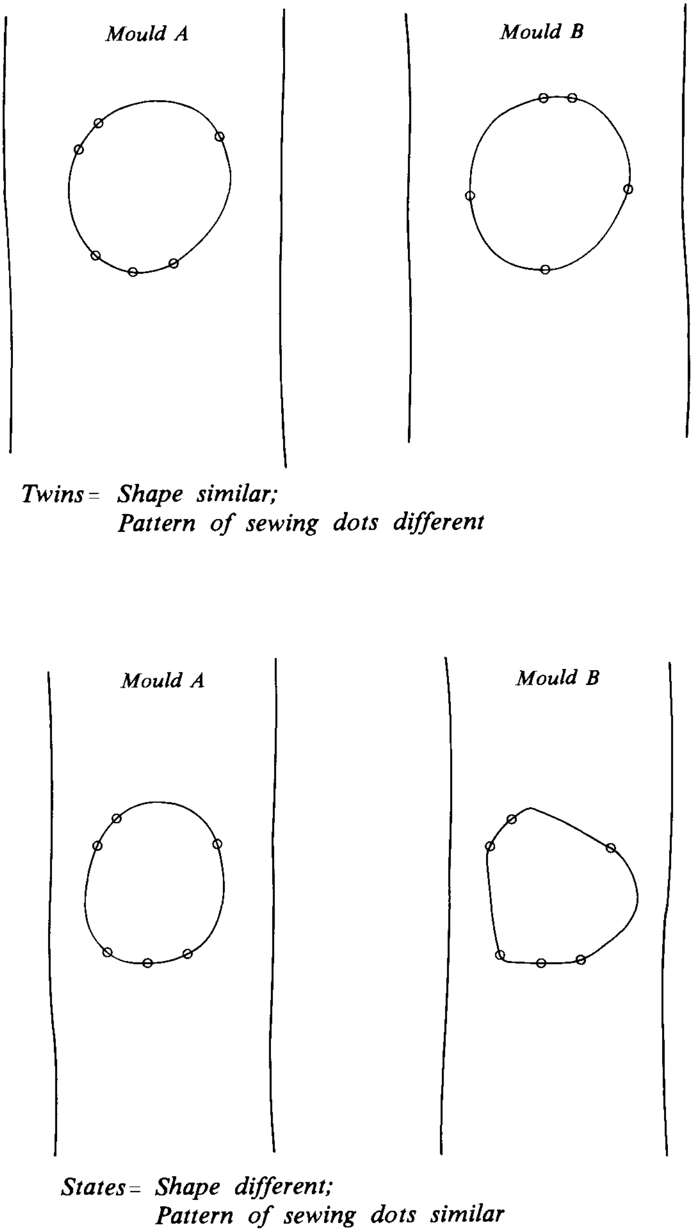
Mould A
Mould B
Twins = Shape similar;
Pattern of sewing dots different
Mould A
Mould B
States = Shape different;
Pattern of sewing dots similar

Figure 4

that are tied to a central chain line—such as in the case of the vast majority of sixteenth-century Italian watermarks—analysis of such movement is not feasible since the variation of the position of the mark between the chain lines is usually not great enough to be measured.

Nevertheless, the stresses placed on the paper mould during its life sometimes cause the shape of the watermark to change subtly, and a continuation of the study using the thirty-nine siren watermarks has shown that minute changes in the shape of a mark can also be recognized using a combination of precise measurement and statistical analysis. The coordinates of twelve control points were chosen on each of the thirty-nine watermarks from the digital image displayed on the image processor, normalized using an affine transformation, and the root mean square (RMS) error was computed that measured how well one set of control points fitted another. These were tabulated in a matrix so that the fit of every watermark on every other watermark within the same mould could be readily seen. (It was found earlier that the RMS values could readily distinguish between two marks from different paper moulds; these values were much higher than for those from the same mould.)

The radiographs of the best and worst fit cases were then carefully examined to establish where the extreme differences lay. In the case of the Martha mould, the extremely subtle difference was seen in the degree of roundness of the left (as we see it) shoulder (see fig. 7). The same is true of the Mary mould, but the angle of the "V" between the fin and right shoulder changes very slightly (see fig. 8). It is hypothesized that, over the life of a mould, such curved wires subject to horizontal pressure in the brushing off of excess pulp from the mould at the end of the day would become increasingly angular.

Correspondingly, we would expect the most curved examples to be the earlier states of the mould. No map on either Martha or Mary paper has yet been found bearing a date after 1570, so we may postulate this as being the end of the mould's life. Of the dated maps bearing the Martha watermark, 1559 is the earliest yet the state of this mark is similar to that of a map dated 1569. If we accept Stevenson's view that paper stocks of normal sizes were used up quite quickly, say within one year, it would therefore seem likely that the life of the Martha (and thus probably also the Mary) mould might reasonably be postulated to be between 1568 and 1570 or perhaps even 1569-1570. This conforms with the evidence presented earlier that toward the end of the decade we see a marked increase in the number of dated maps bearing marks from the Martha and Mary moulds thus considerably narrowing the range given by Beans (1561-1570) and providing a more precise tool than was previously thought.

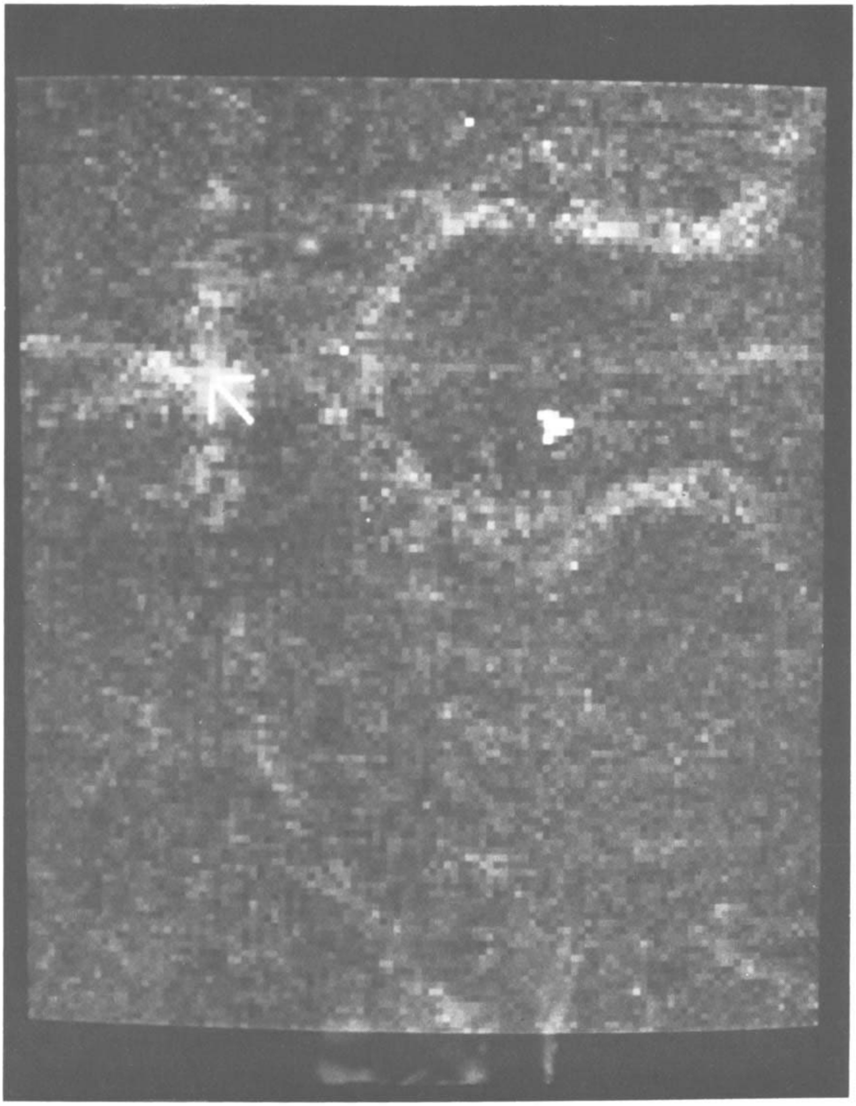

Figure 5

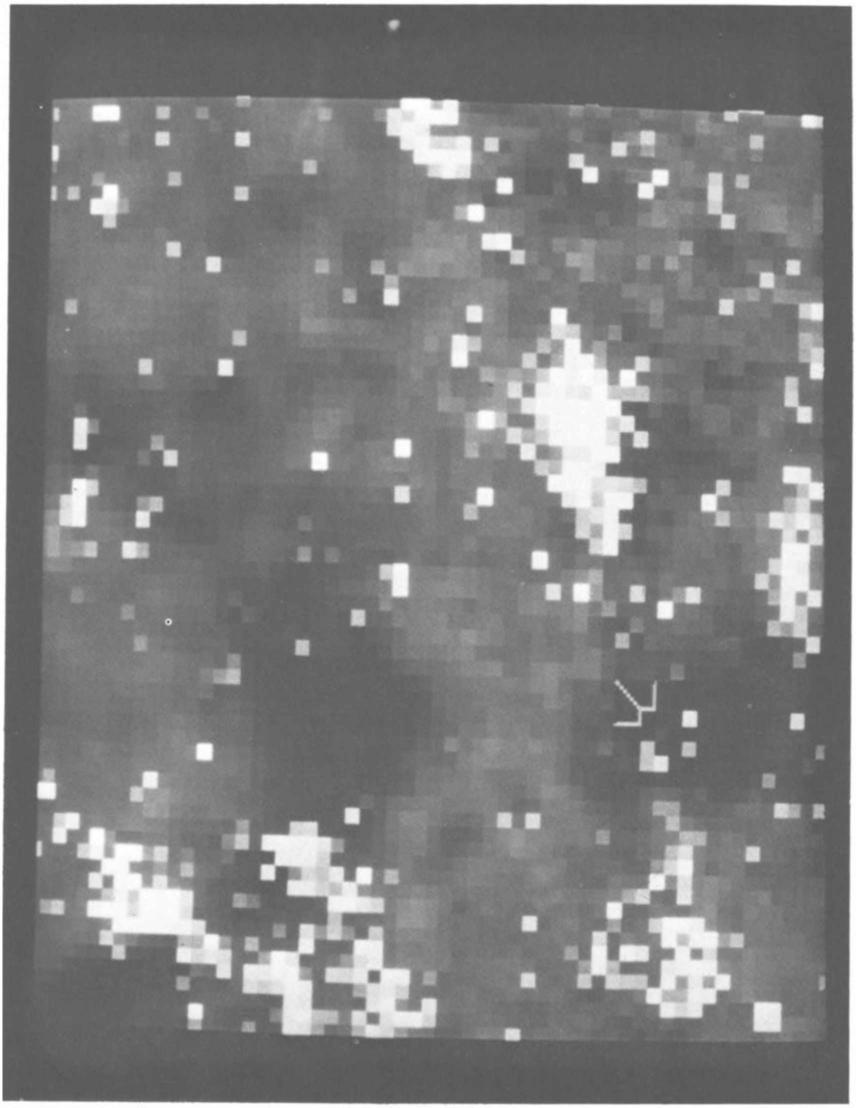

Figure 6

In addition, the author's experiments have shown that the digital scanning of watermarks has certain key advantages. Once the image is scanned, the entire image or sections of it can be manipulated and compared more easily with other similar images. Furthermore, should data banks of watermark images eventually be compiled to replace and enlarge on the manuals of hand-drawn tracings, the digital form of the data may become desirable. With the recent improvements in microcomputers it is now likely that scanned images of lower resolution stored on hard disks will be adequate to perform the analysis.

Beta radiography, however, has now been joined by techniques that measure the percentages of elements in paper. For example, Particle-Induced X-ray Emission has now been used successfully in archaeological and bibliographical work as well as in its more usual biological and chemical applications.[16] A beam of protons is accelerated in a cyclotron, deflected into a vacuum pipe, and narrowed down to a precise beam that can be made less than a millimeter square and aimed at the document in question. In order to avoid placing the document in a vacuum, the beam is passed into a helium or air chamber into which the document is introduced. This improvement, known as "external beam," is essential for the handling of large awkward shaped or precious artifacts including maps and atlases. When aimed at a section of a document—either at the paper, vellum, ink, or pigment—the clashing of particles in the beam with the atoms of the various elements in the object being analyzed excites the atoms in such a way as to generate characteristic X rays which shoot out in all directions. A sample of these is read and the characteristic X rays of each element present in the section of document under analysis are counted, processed by computer, and recorded. In order to avoid bias due to different thicknesses of the material analyzed, the occurrence of an element is expressed as a ratio to calcium, which is a common element in paper of any age.[17]

Each sheet of paper seems to have its unique chemical profile, and the technique is so sensitive that in a study of an eighteenth-century octavo French travel book by a team at the University of California, Davis, the signatures were revealed as groups of eight relatively homogeneous leaves.[18] The sensitivity of this technique was underlined when it is realized that the physicist who drew attention to the periodicity was not previously aware of the occurrence of signatures in printed books.

In a more recent study reported by Eldred, 324 leaves from the first volume of a Gutenberg Bible from St. John's Seminary, Camarillo, California, were analyzed using the UC Davis cyclotron. Calcium again was found to be the most abundant element with smaller amounts of silicon, phosphorus, potassium, sulfur, iron, manganese, copper, and zinc. Three watermarks were found (named *a*, *b*, and *c*) with similar chemical composition in the paper bearing each: *b* was found to have twice the iron of *a* or *c* and twice the manganese of *a*, while *c* was found to have twice the manganese of *a* but a similar amount of iron to *b*. It was thus possible to determine the category of an unwatermarked page from the chemical analysis alone.[19]

The implications of this technique for the study of map paper are several; for the purpose here, examples in the study of sixteenth-century Italian printed maps have been chosen. For these maps, many of which have been extracted from composite atlases with marginal strips pasted to their borders, the technique could easily be used for reconstructing the original content of these atlases by grouping marginal strips of similar chemical composition. In addition, the PIXE data could be used to answer a series of questions about the chemical variation of papers with the same watermark, its twin, or its variant of the same design. Papers bearing the same watermark from several different document types, such as printed books or prints, could also be analyzed. Perhaps most importantly, papers of similar chemical content with different watermarks might be searched for, establishing the association of multiple watermark designs using a common papermaker's vat at a given time. Finally, were enough data gathered, what Schwab has called a "systematic chemical-bibliographical grid" could be compiled for a given period into which samples of unknown origin could be placed.[20]

The main problem with the analysis of paper is that it dates the paper and not the impression. While Stevenson attempted to allay fears about this, the skepticism remains. With enough data on the chemical composition of the paper, however, along with analysis of the other physical component of the document—the ink—both interpreted within their general publishing context, it might indeed be possible to arrive at a good estimate for the average shelf life of a sheet of paper between paper mould and printing press and thus an indication of the precision by which impressions may be dated from an analysis of the paper which carries them.

Ink

Unlike the analysis of paper, the analysis of printing ink on maps provides information about the circumstances of the impression and printing rather than the papermaking and is thus a more directly useful form of evidence. Yet if the history of paper is an obscure area of study, the study of printing ink as a historical source of evidence is far more obscure, largely because the methods of analyzing it have not been

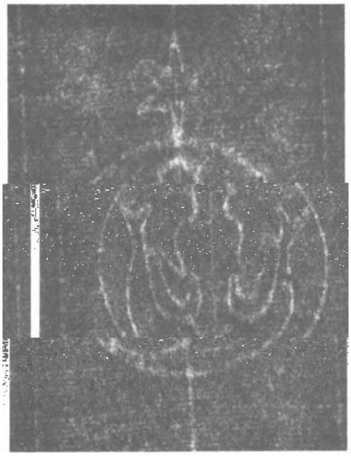

Figure 7

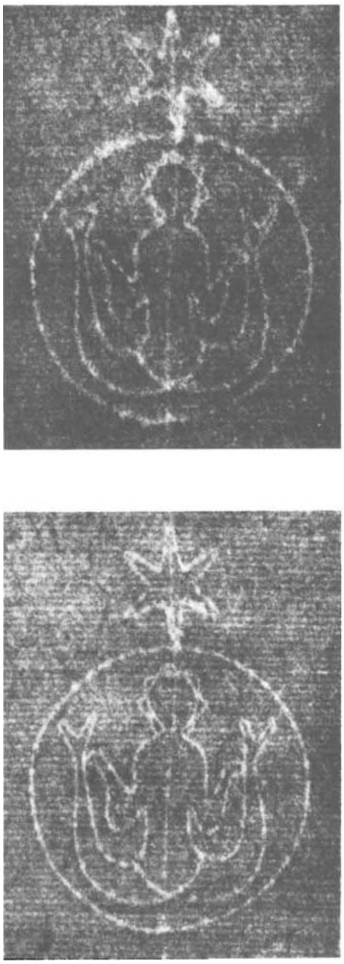

Figure 8

available until very recently.[21] One reason given for the delay in studying the Vinland Map inks in the late 1960s, for example, was that improvements in microspectroscopy had to be awaited before the analysis could be completed. The more recent PIXE or XRF techniques have now radically changed the situation.

The series of studies recently carried out using PIXE at the University of California, Davis, with various copies of the forty-two line Gutenberg Bible, thirty-six line Bible, and other documents reveal an astonishing sensitivity of the technique in analyzing printing ink composition. The analysis revealed details of the day-to-day organization of the printing of the first volume of the forty-two line Bible with such precision that the number of production crews—six—could be concluded as well as the times when the work was shifted around to keep them busy.[22] A technique capable of providing conclusions of such minute technical detail could clearly add an important dimension to the physical analysis of maps. The Vinland Map, for example, could now be subjected to the proton beam without fear of damage. The examination of the map in 1974 by McCrone Associates in Chicago had revealed substantial amounts of a particular precipitated form of titanium dioxide that was only commercially available in the twentieth century.[23] The cyclotron at the University of California, Davis, however, revealed titanium dioxide in only trace amounts, once again opening the question of the map's authenticity.[24]

The technique has obvious applications in the study of sixteenth-century Italian printed maps. For example, key ratios of the composition of ink could be plotted against key ratios of paper composition, and the resulting clusters would indicate which certain combinations were active. Should these clusters also be related to the printing of certain map plates or particular centers of the map trade (for example, Venice); further conclusions could be drawn. Composite atlases suspected of being partially printed at once (such as a Venetian atlas in The Newberry Library previously described by the author) could be analyzed with this method to confirm this idea.[25] Furthermore, by calibrating the watermark data with the proton analysis, a clearer estimate of the reliability of watermark evidence in dating could be achieved.

Competing with the PIXE technique is energy dispersive X-ray fluorescence which has been in wide use in analytical chemistry since about 1950, and which has been in use for the study of archaeological and fine arts objects for several years.[26] Both wavelength and energy dispersive systems have been used, but only the latter may be nondestructive. In the energy dispersive system, an X-ray beam is focused on a thin surface layer of the sample which fluoresces in all directions producing electrical pulses whose magnitude is unique to each element present in the sample. A detector close to the source senses some of these pulses, which are counted and processed (usually by a microcomputer) to provide proportions of elements above sodium (atomic number 11). Some units have different ranges depending on whether the sample is placed in air or helium.

At the Winterthur Museum in Wilmington, Delaware, studies of paper and graphic objects have been carried out with success since 1973, enabling the staff to obtain recognizable spectral patterns for papers from specific paper mills made over several decades. The technique is even valuable for nineteenth-century artifacts—by detecting the presence of zinc or copper uniformly distributed over a lithographic print, the composition of the printing plate can be deduced. Lithographs free of zinc or copper are thus assumed to have been printed from stone thus predating the lithographic transfers from metallic plates. This application for the recognition of the states of late nineteenth-century lithographic maps is clearly promising.[27]

More recently, Gary Carriveau of the Detroit Institute of Arts has used XRF for an analysis of the pigments on several Rembrandt drawings finding that a recent unrecorded restoration on one had been carried out using a pigment containing titanium dioxide.[28] The Detroit XRF equipment was also used in a study by Bèla Nagy who analyzed several pigments on selected European maps from the fifteenth to the nineteenth centuries, clearly demonstrating the value of the technique for detecting modern color. For example, on a 1681 map of Lombardy by Cantelli da Vignola, a number of nineteenth- and twentieth-century pigments were found, namely zinc white, titanium white, and barium white.[29]

Equally as important as the availability of the equipment are the concerns of curators and librarians in protecting artifacts from irreversible damage. According to Cahill, no technique other than external beam PIXE and XRF seems to fulfill this essential requirement.[30] Chemical or electron beam methods which have necessitated destroying samples of the artifact, however small (such as the X-ray diffraction and electron microscopy used for the Vinland Map) would now appear to be less desirable.

Another group of factors includes the technical requirements of the analysis such as target area size, system sensitivity, errors caused by unevenness in the sample's surface, and range of elements detectable. PIXE can detect, in principle, all elements between sodium and uranium in a single irradiation. Depending on the unit, XRF can only detect about thirty of these elements above chlorine (atomic number 17), although recent models with the sample placed in helium can detect above sodium. The accuracy of PIXE (±5 or ±2 percent for thin targets) also exceeds that of XRF in equivalent irradiation time. The unevenness of the sample's surface has an effect on accuracy in both XRF and in PIXE. We must await further experience with the analysis of historical papers and inks to determine the level of sensitivity required, although Hanson reports that XRF provides data well within the needs of the Winterthur staff for the purpose of detecting forgeries in general museum artifacts.[31]

The main advantage of PIXE over XRF at present seems to be in the size of the target analyzed at equivalent times of irradiation. PIXE can focus to 1mm in an exposure of thirty seconds, but this would take much longer for XRF. Exposure time was about 5 minutes for a 5mm diameter target area in the Nagy study, but in order for this to be focused to 1mm, the irradiation time would have to be about 125 minutes. The sensitivity desired must therefore be weighed against the time and expense of the analysis. Since the composition of the sample is averaged over the target area, more sensitive readings will result from a smaller target area. In maps analysis, this is a prime consideration as the ink is frequently found only on very thin lines. Pigments may also be found confined in small areas. For a general analysis of large paper or pigment areas, however, XRF may be adequate for the research at hand. The sensitivity and viewing area of the XRF technique is, however, rapidly improving, and it might well provide a valuable alternative to the PIXE technique, particularly for cases where larger areas can be sampled or the precision requirements are not as stringent.

If external beam PIXE can identify a batch or even a sheet of paper with a unique chemical fingerprint, to say nothing of the ink, what future is there for watermark analysis? On the surface it might appear that all current projects for compiling albums of watermark images should be discontinued in favor of systematic PIXE or XRF analysis of whole groups of documents from various periods and origins. But it is equally desirable to compile files of watermark images preferably using prints from beta radiography negatives reproduced at full-size. The reason is that for many purposes (such as the determination of forgeries) a dating precision of only a few years may be necessary. In addition, for the analysis of an occasional suspect document, a quick beta radiograph or other watermark image is more feasible than an individual analysis by XRF or PIXE, even if the latter were available locally.

Furthermore, the systematic collection of watermark images flags those documents that are suitable candidates for PIXE or XRF analysis. For example, a PIXE analysis of all thirty-nine of the sixteenth-century

Italian siren watermarks in the author's recent work, together with additional similar marks gathered from books and prints, would demonstrate the variation in composition of the batches created with this particular pair of watermarks. This might demonstrate that only a sample of papers of a given watermark might need PIXE analysis. Should the ink in maps, books, and prints of particular printers be found to correlate with batches of paper bearing such watermarks, further confirmation might also be found of the author's narrowing of the date of appearance of maps appearing on this paper to 1568-70.

The main limiting factor of all scientific methods of analysis at present is that a sufficient fund of characteristic data has yet to be built up. The information relating to the chemical content of paper or ink means little in isolation; it needs to be related to the norms for a particular period, printer, or papermaker. Considerable institutional cooperation will be necessary if this information is to be gathered systematically and in a consistent format. If beta radiograph images were stored digitally, for example, they would be accessible by telecommunications. Statistical data relating to the content of paper, ink, and pigment should also be made available in digital form. Despite the apparent immensity of the task, it is not too early to start to compile specifications for such a data bank, which, if coordinated by a major library or institution, would constitute an impressive resource not only for historians of cartography but also for all researchers, conservators, archivists, librarians, and others who need access to precise physical information about the documents that come into their hands.

ACKNOWLEDGMENTS

This article was previously published as a chapter entitled "The Analysis of Paper and Ink in Early Maps: Opportunities and Realities." In *Essays in Paper Analysis*, edited by Stephen Spector, pp. 200-21. Washington, D.C.: The Folger Shakespeare Library, 1987, and is here reprinted by kind permission of Associated University Presses. The author would also like to express his thanks to the John Simon Guggenheim Memorial Foundation and the Graduate School of the University of Wisconsin—Madison for support toward this study.

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2. Woodward, David. "The Form of Maps: An Introductory Framework." In *AB Bookman's Yearbook, Part One: The New and the Old.* Clifton, N.J.: AB Bookman's Weekly, 1976, pp. 11-20.

3. While they are not strictly physical components, the marks themselves (ink lines, patches of color) have physical characteristics that can be measured to provide clues to the origin or dating of documents. For example, microphotography of the impressions has been used to order states of Hogarth prints, and enhancement of writing on manuscripts has been carried out by Benton, et al. See Benton, John F., et al. "Digital Image-Processing Applied to the Photography of Manuscripts." *Scriptorium* 19(1979):40-55. Additional physical components might include adventitious matter such as dirt, stains, etc., some of which may reveal the history of a particular document. Arthur Baynes-Cope has summarized the physical components of documents in "The Scientific Examination of the Vinland Map at the Research Laboratory of the British Museum." *Geograpical Journal* 140(June 1974):208-11. Additional terms for these components (none of which has yet entirely been accepted in the literature) are discussed in Woodward, "The Form of Maps."

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14. The assistance of Frank Scarpace, Pete Weiler, and Mark Olsen is gratefully acknowledged.

15. Scanning was performed on an Optronics Photomation System P-1700 scanning microdensitometer with a resolution of 500 x 700 picture elements. The images were processed on a Stanford 170 Digital Image Processor.

16. For a general discussion of PIXE, see Cahill, T.A. "Proton Microprobes and Particle-Induced X-Ray Analytical Systems." In *Annual Review of Nuclear Particle Science,* edited by J.D. Jackson, et al., pp. 211-52. Palo Alto, Calif.: Annual Reviews Inc., 1980.

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20. Schwab, "The Cyclotron and Descriptive Bibliography," p. 9.

21. See, however, the excellent bibliography in De Pas, Monique, and Flieder, Françoise. *Historique et perspectives d'analyse des encres noires manuscrites* (Réunion du Comité de l'ICOM pour la Conservation, Madrid 2-7 Oct. 1972). Rome: International Center for Conservation, 1972.

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30. Cahill, "Proton Microprobes and Particle-Induced X-Ray Analytical Systems."

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