has to date, that will provide an additional clue to the origin of the artifact in question. But a more promising path may lie in our ability to relate single—or, if possible, multiple—copies of different states of key copper plates (or 'leader maps' as they may be called) to the paper types on which they appear. These intersections of the plate and paper data will help to anchor the paper data for use in dating maps that do not have multiple identifiable states.

Conclusions

The conclusions relate both to the precision of the proton milliprobe method employed and to the efficacy of using watermark data to analyze sixteenth century Italian maps. The analysis of key elements in the paper using the PIXE technique has proved to be sensitive enough to identify a given batch of paper so that twin moulds can be identified. A test of several readings from the same sheet of paper also confirmed both the high precision of the technique and the internal consistency of a paper sheet.

The PIXE data indicates an extremely close correlation between the watermark and the percentage of certain elements in the paper. Using discriminant analysis, whenever two watermark groups were examined, they were invariably found to be distinct. When all the variables were treated altogether, the technique's ability to discriminate was less efficient, but this causes no major drawback to the analysis for the purposes of this study. The general conclusion is that watermarks may be used as a far more reliable and precise way to identify map paper than was previously believed. Their use will thus constitute a major part of an ongoing attempt to use physical, historical and geographical evidence of the original maps to reconstruct the pattern of paper sources and plate borrowing in the sixteenth century Italian map trade.

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References

1. Cahill, T. A., 'Proton milliprobes and particle-induced X-ray analytical systems', *Annual Review of Nuclear Particle Science,* 30 (1980), pp. 211–252.
2. Woodward, D., 'New bibliographical approaches to the history of sixteenth century Italian map publishing' (unpublished paper delivered to the 8th International Conference on the History of Cartography, Berlin, 1979).
3. Cahill, T. A. *et al.,* 'Gutenberg's inks and papers: non-destructive compositional analysis by proton milliprobe', *Archaeometry,* 26 (1984), pp. 3–14; Schwab, R. N. *et al.,* 'Ink patterns in the Gutenberg New Testament: The proton milliprobe analyses of the Lilly Library copy', *Papers of the Bibliographical Society of America,* 80 (1986), pp. 305–331.
4. Tooley, R. V. 'Maps in Italian atlases of the sixteenth century', *Imago Mundi,* 3 (1939), pp. 12–47.
5. Woodward, D., 'New tools for the study of watermarks on sixteenth century Italian printed maps: Beta radiography and scanning densitometry' in Marzoli, Carla Clivio (ed.), *Imago et Mensura Mundi: Atti del IX Congresso Internazionale di Storia della Cartografia,* 2 vols., (Rome: Istituto della Enciclopedia Italiana, 1985), 2, pp. 541–152 and his 'The analysis of paper and ink in early maps: opportunities and realities', in Spector, Stephen (ed.), *Essays in paper analysis* (Washington, D.C.: Folger Books, 1987), pp. 200–221.
6. Briquet, C. M., *Les filigranes,* edited by Allan Stevenson (Hilversum: Paper Publications Society, 1968); Heawood, Edward, *Watermarks, mainly of the seventeenth and eighteenth centuries* (Hilversum: Paper Publications Society, 1950); Aurelio Zonghi, Aurelio, et al., *Zonghi's watermarks* (Hilversum: Paper Publications Society, 1953); Beans, George H., *Some sixteenth century watermarks found in maps prevalent in the IATO atlases* (Jenkintown, Pennsylvania: published by the author, 1938).
7. Schoonover, D., 'Techniques of reproducing watermarks: a practical introduction', in Spector, Stephen, ed., *Essays in Paper Analysis,* pp. 154–164.
8. Woodward, D., 'New bibliographical approaches to the history of sixteenth century Italian map publishing'.

9. SPSS Inc, *SPSS-X: User's guide,* Chicago; (McGraw-Hill, 2nd. ed., 1986), ch. 36.
10. For more detailed descriptions, see Klecka, W. R. 'Discriminant analysis' in *Statistical package for the social sciences,* ed. N. Nie (New York: McGraw-Hill, 1975), pp. 434–448; Clark, W. A. V. and Hosking, P., *Statistical methods for geographers* (New York: John Wiley, 1986), pp. 479–498, and Thompson, C. and Buttenfield, B., *Discriminant analysis in geography,* Concepts and Techniques in Modern Geography Series (Norwich, UK: Geo Books, forthcoming).
11. Woodward, D. 'New tools for the study of watermarks on sixteenth century Italian printed maps: Beta radiography and scanning densitometry,' in Marzoli, C. C. (ed.), *Op. cit.,* 2, pp. 541–552.

The International Map Collectors' Society

The annual IMCoS programme continues to grow fuller and more interesting. The venue for the Annual Symposium in June 1989 was once more The British Library, under the very able chairmanship of Tony Campbell. Four good papers were accompanied by a visit to the exhibition 'What use is a Map?', the theme of the symposium, and a demonstration of the 'On-Line' Map Catalogue. In October 1989 a large number of members gathered in Athens for the Seventh Annual International Symposium. The meticulous arrangements by our International Secretary Themis Strongilos ensured a most enjoyable visit for the more than fifty members from abroad, and we were able to meet a similar number from the Society for Hellenic Cartography, led by Professor Catherine Koumarianou. Visits were made to three specially hosted exhibitions: 'Ptolemy Maps of Greece' at the Gennadius Library, 'Cypriote Cartography from Claudius Ptolemaus to Kitchener' at the Museum for Cycladic and Ancient Greek Art, and 'The Cartography of the Shores and Islands of Greece' at the National Gallery. The weekend was completed with a visit to the Vorres Museum, an enchanted home of modern art and imaginative landscaping.

A new, and very successful, venue was established for the Map Fair in London in June–the New Connaught Rooms at Holborn. Many visitors were meeting IMCoS for the first time, and the membership increased as a result. Tony Burgess and Eugene Burden prepared an exhibition of unusual and 'secondary' maps on loan from IMCoS members which was enjoyed by those not too busy selling or buying maps. In May members visited the Royal Geographical Society for a special viewing of the 'William and Mary' exhibition. The autumn meeting was held at York at the historic St William's College and included three most interesting papers and a visit to an exhibition of maps at the York Minster Library.

The IMCoS-Tooley Award for 1989 was made to Eila Campbell for her outstanding contribution to education in the history of cartography and her wide cartographical interests. She has been influential in this field for many years, and her achievements are well known. For the first time IMCoS participated in the British Library's 'Adopt a Book' scheme, and *De Nieuwe Groote Lichtende Zee-Fakel,* Van Keulen 1697, was selected for repair and conservation.

Future years promise to be equally busy for IMCoS members. The Eighth Annual International Symposium will be hosted by the Washington Map Society in October, 1990. The venue for the June 1991 Annual Symposium will move from London to Edinburgh, hosted by the National Library for Scotland, and in November 1991 members are invited to a double symposium: three days at Singapore followed the following week by a visit to the Australian Map Society at Sydney. Regional meetings in England are also planned.

London, January 1990. Susan Gole
Executive Chairman of IMCoS

The Correlation of Watermark and Paper Chemistry in Sixteenth Century Italian Printed Maps

By DAVID WOODWARD

In describing printed maps, the difference between the map as image and the map as artifact has often been ignored. A map may be described as being 'sixteenth century', for example, when it is quite clear from the paper on which it was printed that it is a nineteenth century impression from an existing plate or block. To those who are interested only in the image, as long as the historical or geographical content is clear, this issue seems irrelevant. As long as every line and letter is legibly reproduced, it makes no difference to them whether the map was printed in a Renaissance workshop or a twentieth century offset press. To the historian of cartography who is interested in the map as a window on social, cultural and economic history, however, the task of placing the artifact correctly in the original milieu of its creation becomes of utmost importance. These issues are raised here in the context of the sixteenth century map trade to help us understand the shop methods, institutional structure, and historical geography of Renaissance map publishing in the period 1540–1580.

The analysis of any printed map as an artifact requires three separate supporting pieces of evidence: that of the printing surface, here a copper plate, which goes through an identifiable series of stages in its life, usually called states; the material on which it is printed, here paper, which also goes through identifiable stages of the mould on which it was made; and the medium in which the plate makes a mark on the paper, here copperplate ink. If the characteristics of these three things—plate, paper and ink—can be observed and measured and their intersections plotted, we may be able to trace their origin, and hence the origin of the map which they constitute.

This paper describes some initial observations and calibrations of two of these variables, ink and paper, and lays out a methodology for how the third variable—the plates—can be incorporated into the analysis. The subject of the investigation was one atlas of 41 maps and 115 separate maps from the Novacco Collection at the Newberry Library in Chicago—all printed from copper plates in Italy in the sixteenth century. The method employed, which has been described elsewhere[1] was particle-induced X-ray emission (PIXE) with a proton milliprobe at the University of California—Davis' Crocker Nuclear Laboratory. Two separate testing sessions took place in May 1987 and June 1988 under the auspices of the Crocker Historical and Archaeological Project, which makes available the use of the cyclotron for the analysis of historical artifacts. I have previously described a Venetian composite atlas in the Newberry Library in which many of the maps appear to have been printed in the same place on the same batch of paper bearing the twin watermarks of an eight-spoked wheel.[2] Fig. 1 shows the clustering of the paper with this watermark in a statistical 'space' defined by axes representing the measured ratios of iron, calcium and potassium to argon:

Samples of ink from each map were taken with the proton milliprobe and the chemical elements of iron and copper are summarized in the notched box plots in Figs. 2 and 3. The figures have been standardized as ratios to Argon, a standard procedure in PIXE.

Contrary to expectations, the variation in the ink used to print the maps on the similar paper was greater than that in the rest of the sample. A tentative conclusion is that copperplate inks appear to be highly variable within a given batch and thus even across a single map. This is in contrast to letterpress inks, whose batches varied considerably according to each printer's recipe and whose internal consistency was remarkable even within each batch, as the remarkable work on the printing of the Gutenberg Bible has shown.[3]

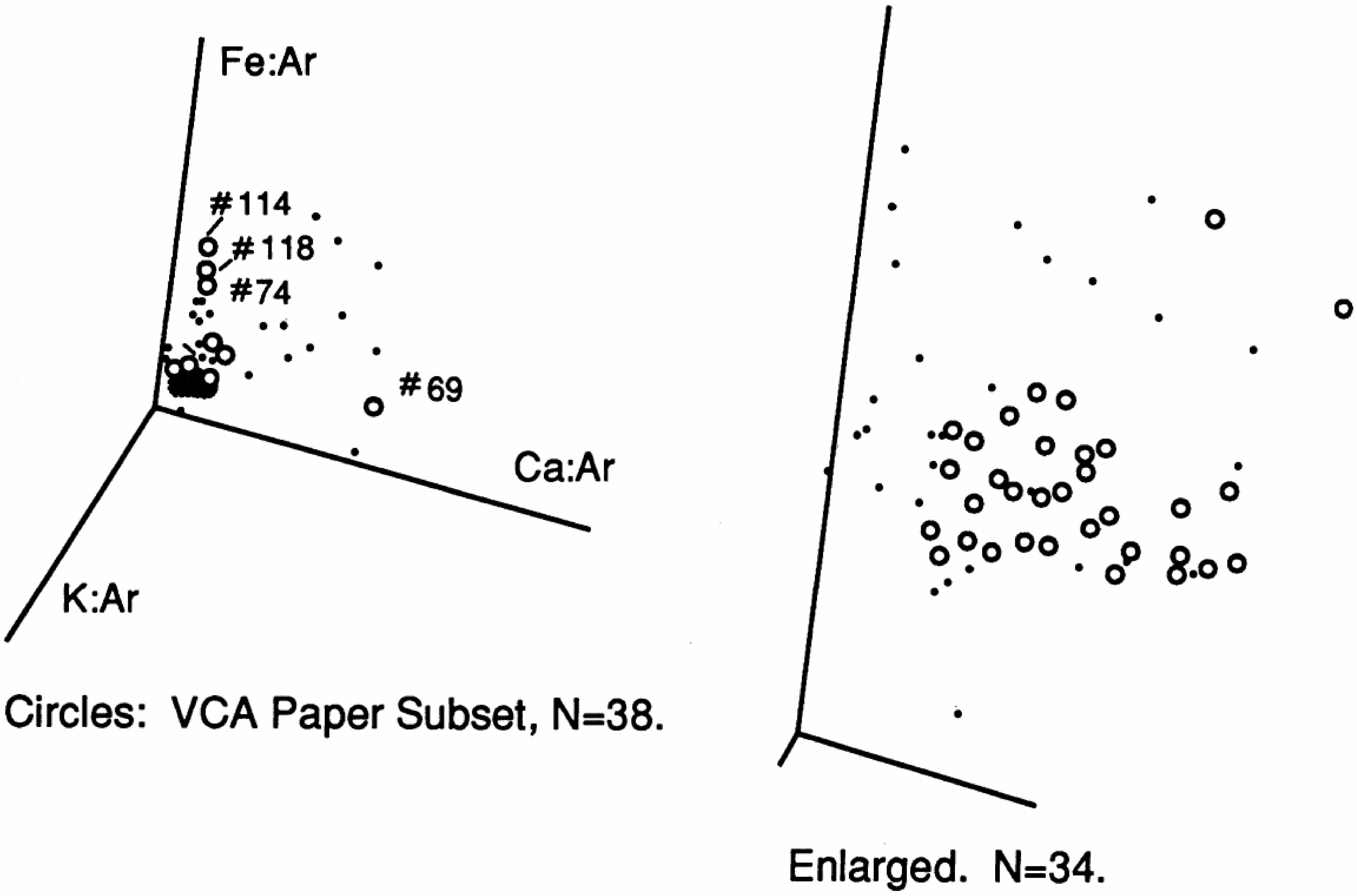

Fig. 1. Clustering of paper with eight-spoked wheel watermark in a statistical 'space' defined by axes representing the measured ratios to argon of iron, calcium, and potassium in the paper of a Venetian composite atlas in the Newberry Library.

Although the recipes for these copperplate inks used by Italian map printers must have varied, the internal variation within the batch is probably greater than or at least comparable to the variation between batches. It thus appears that—although more systematic investigation of copperplate ink is certainly warranted—at this stage it seemed that a chemical analysis of the map papers would provide clearer results.

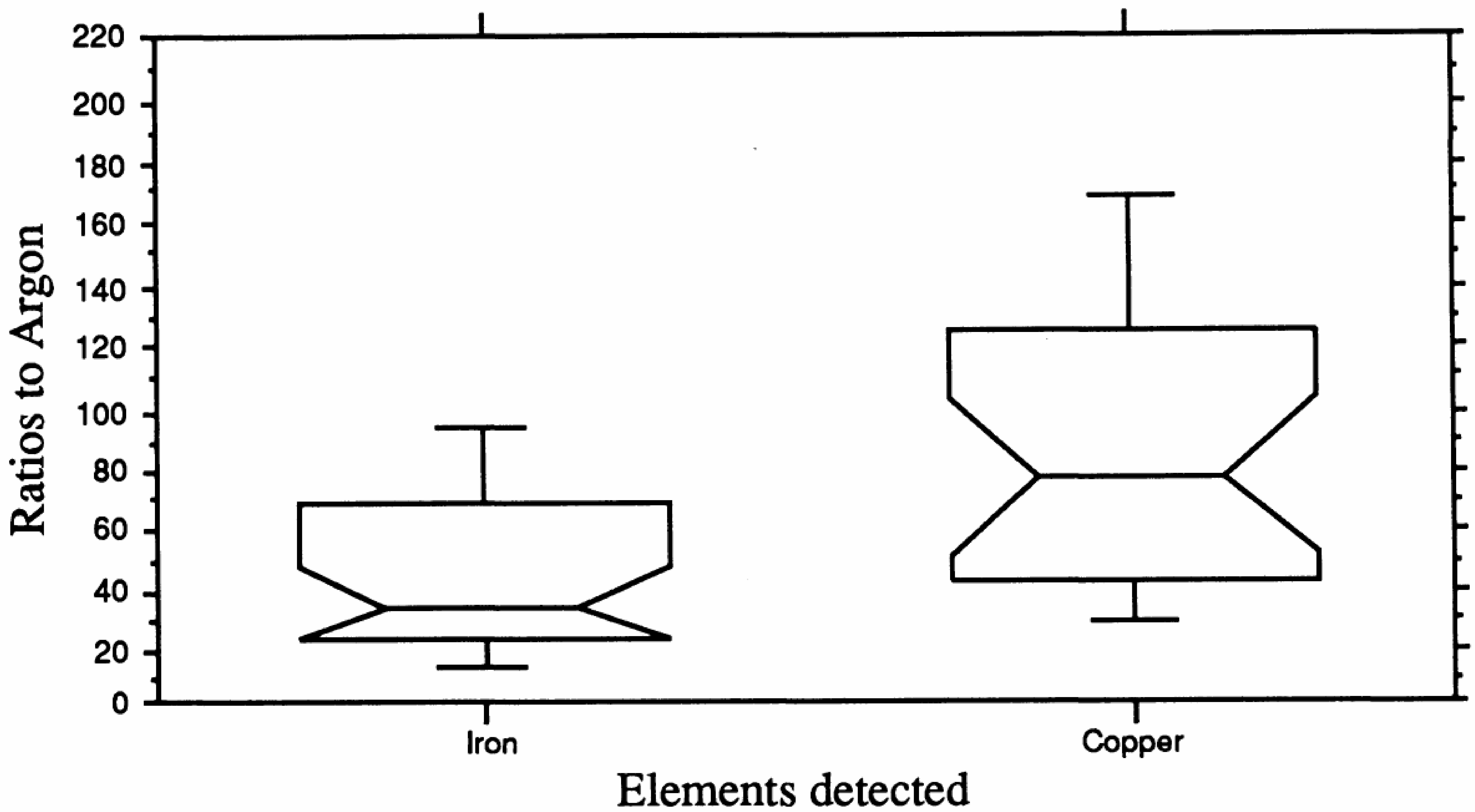

Fig. 2. Variability of ink in wheel-watermarked paper. The notched box plots are useful graphical ways of comparing medians, interquartile ranges, and data extremes.

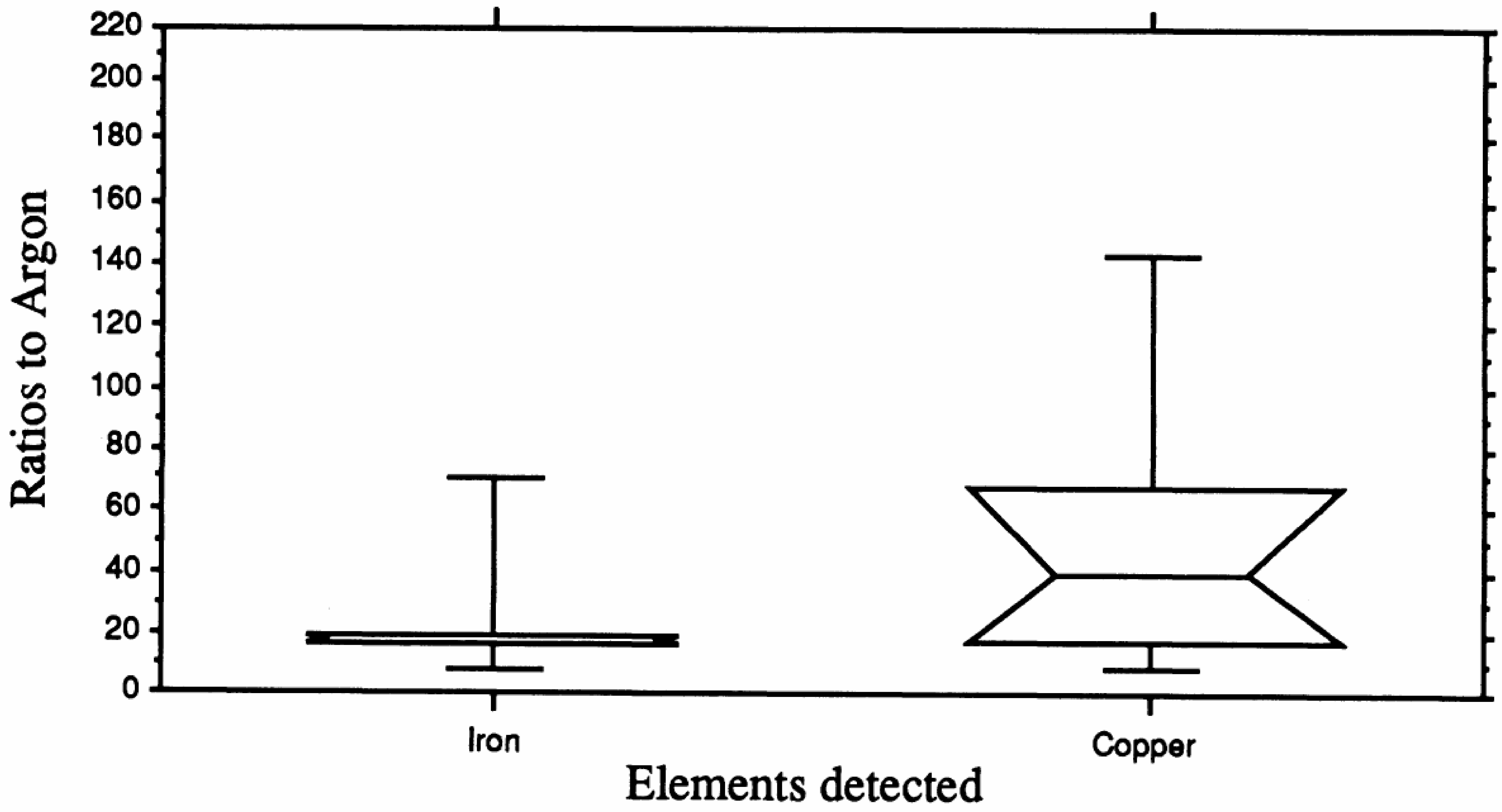

Fig. 3. Variability of ink in rest of sample.

Paper

In contrast to copperplate inks, the paper used in the maps studied appears to be remarkably consistent across the sheet. To assess the repeatability of readings of the proton milliprobe, thirteen observations in different parts of Novacco map 4F165, a map of Germany by Giacomo Gastaldi, 1552 (Tooley 250[4]) were compared with the other 116 observations of paper elements made during the second run (1988).

For each of four variables (potassium, calcium, manganese, and iron, each standardized with respect to argon), the mean, standard deviation, and standard error were calculated. No test was done which involved an actual measurement of statistical significance; the idea was to show the consistency of the test observations, not their difference from the rest of the observations. The salient results were:

Variable	mean	std dev.	std. error
K: Ar			
test	3.526	0.351	0.133
rest	6.017	2.841	0.298
Ca: Ar			
test	14.20	1.321	0.366
rest	16.38	9.566	0.888
Mn: Ar			
test	3.1	0.682	0.197
rest	2.897	1.474	0.143
Fe: Ar			
test	7.5792	1.3140	0.364
rest	13.799	7.458	0.692

Table 1: Comparison of elements of paper of a single sheet with those in the rest of the sample.

The results are displayed in the notched box plots in Figs. 4 and 5. With one exception, manganese (in which the range of amounts detected is anyway too small to be useful), the standard deviations of the test data were well below those of the rest of the observations. The standard error of the test data is about half that of the rest of the sample, except for manganese. It may be argued, then, that the chemical constitution of paper can be taken as constant across

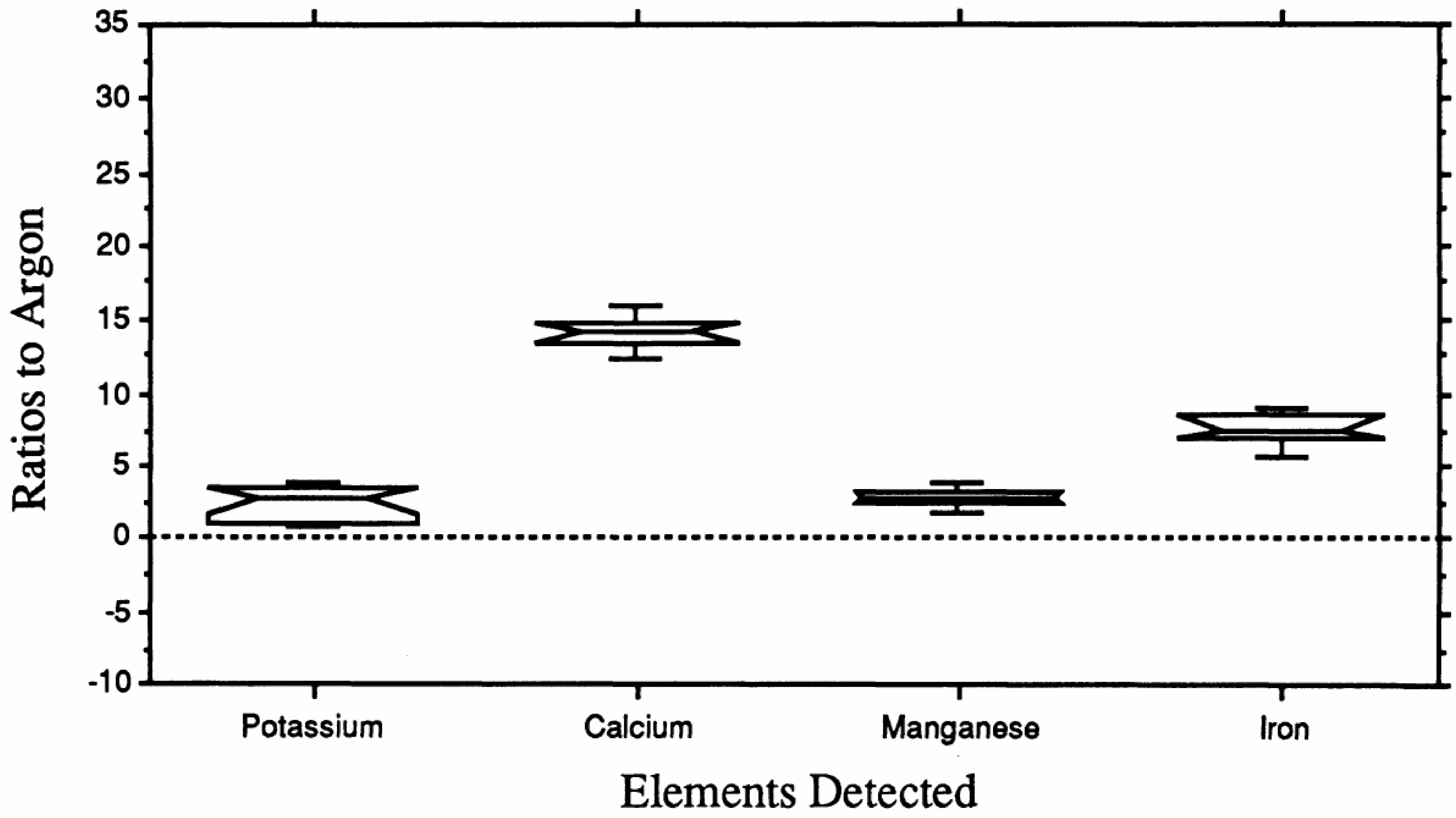

Fig. 4. Variability of paper in Novacco Map 4F165.

a single sheet and that the elements potassium, calcium and iron display the greatest ranges of values and thus may be the most valuable to detecting changes between paper types. At the same time, the test represents a confirmation of the consistency and precision of the PIXE technique.

Paper and watermarks

Clearly, it is not always practical to expect map historians to subject their maps to cyclotron analysis. The University of California—Davis facility is one of the very few adapted for such a purpose, and the expected returns ar enot likely to justify the expense and inconvenience. If,

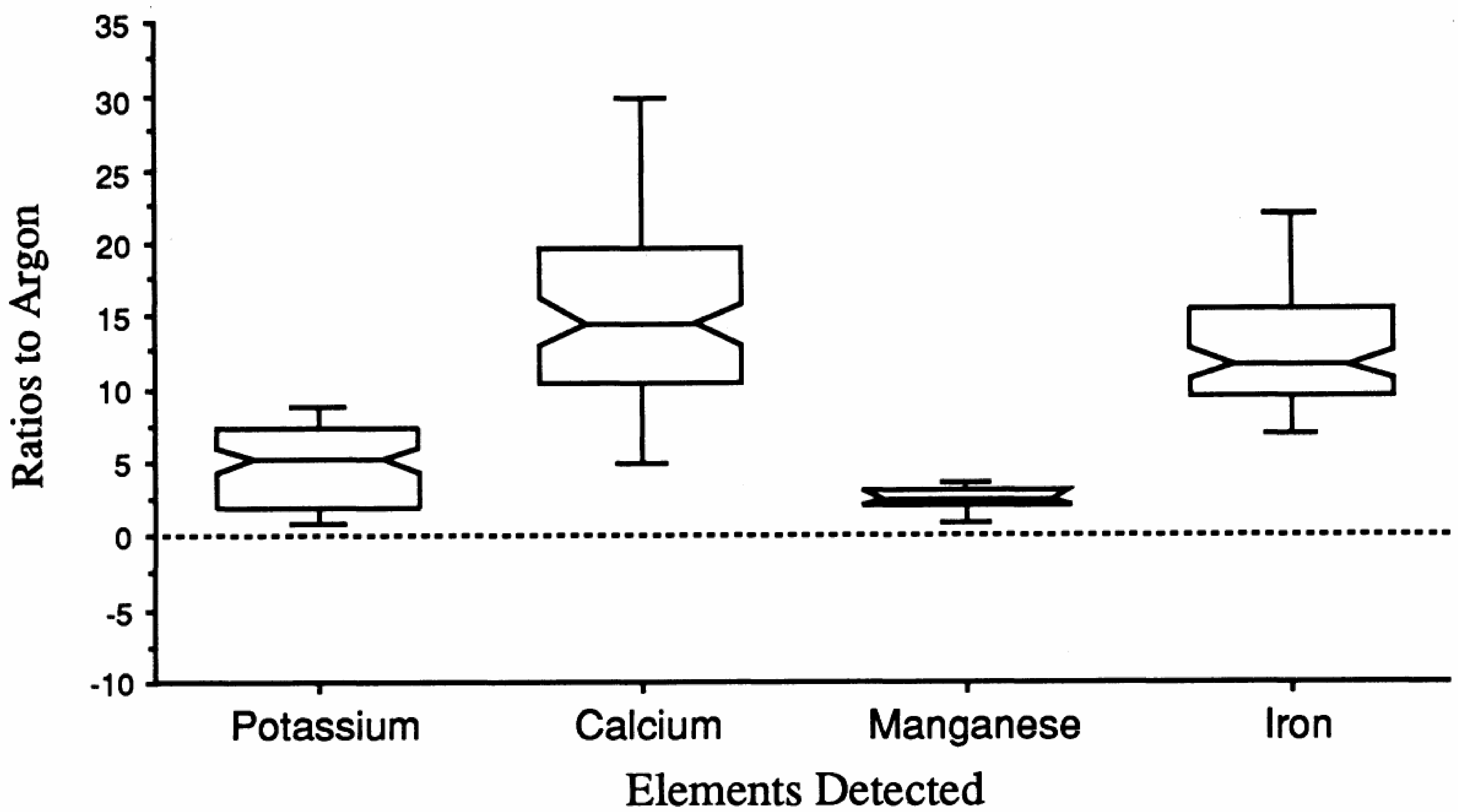

Fig. 5. Variability of paper in rest of sample.

however, it could be shown that a readily available piece of evidence—that of the image of the map watermark—could be relied on with some confidence to represent differences in paper chemistry, this would simplify analysis considerably.

Fortunately, the paper of mid-sixteenth century Italy is rich in watermarks, and a description of their origin and possible use may be found elsewhere.[5] The salient point to consider here is that a given watermark is unique to a particular paper mould, and minute differences in its shape and position may even give clues to the state of the mould. Tests were therefore run to establish whether or not paper made from the same mould was chemically consistent and significantly different than that made from another mould.

Three clarifications are first in order:

(1) It is now possible to identify a given paper mould—even the state of a given paper mould—with photographic or radiographic methods of reproduction. Thus the limitations of hand tracing that plagued early watermark studies left scholars never certain whether what they had was exactly the same as that illustrated in C. M. Briquet *Les Filigranes* or other manuals.[6] This opened the door to skeptics, who claimed that watermark designs could be copied and used over decades and were thus imprecise aids to the identification of the place and date of the paper's manufacture. The use of beta radiography or other methods of watermark imaging have removed several of these objections.[7] It is now necessary to distinguish between the watermark design and the watermark as an indicator of the paper mould.

(2) Paper was routinely made from twin moulds used in tandem, and thus it is perfectly possible for two slightly different watermarks to have used the same batch of paper.

(3) Although it is necessary to bear in mind in work of this type that it is the paper, not the map, that is being described by these methods, I have argued elsewhere that several factors acted against large batches of paper standing around waiting to be printed.[8]

Plan of the study

In order to establish whether or not paper made from a given paper mould is chemically consistent, maps with paper known to have been made from eight different paper moulds were tested with the proton milliprobe. Potassium, calcium, and iron seemed to be the most significant elements, but manganese and copper were also included in the analysis. The identified paper moulds formed the categories shown in Table 2, with a sample in Fig. 6.

The data were analyzed using 'discriminant analysis', with the aid of an SPSS-X package program[9] and a VAX computer. Discriminant analysis ('DA') is a multivariate statistical technique for studying differences between two or more mutually exclusive groups of objects with respect to several variables simultaneously. Originally developed by Fisher in the 1930s, it has

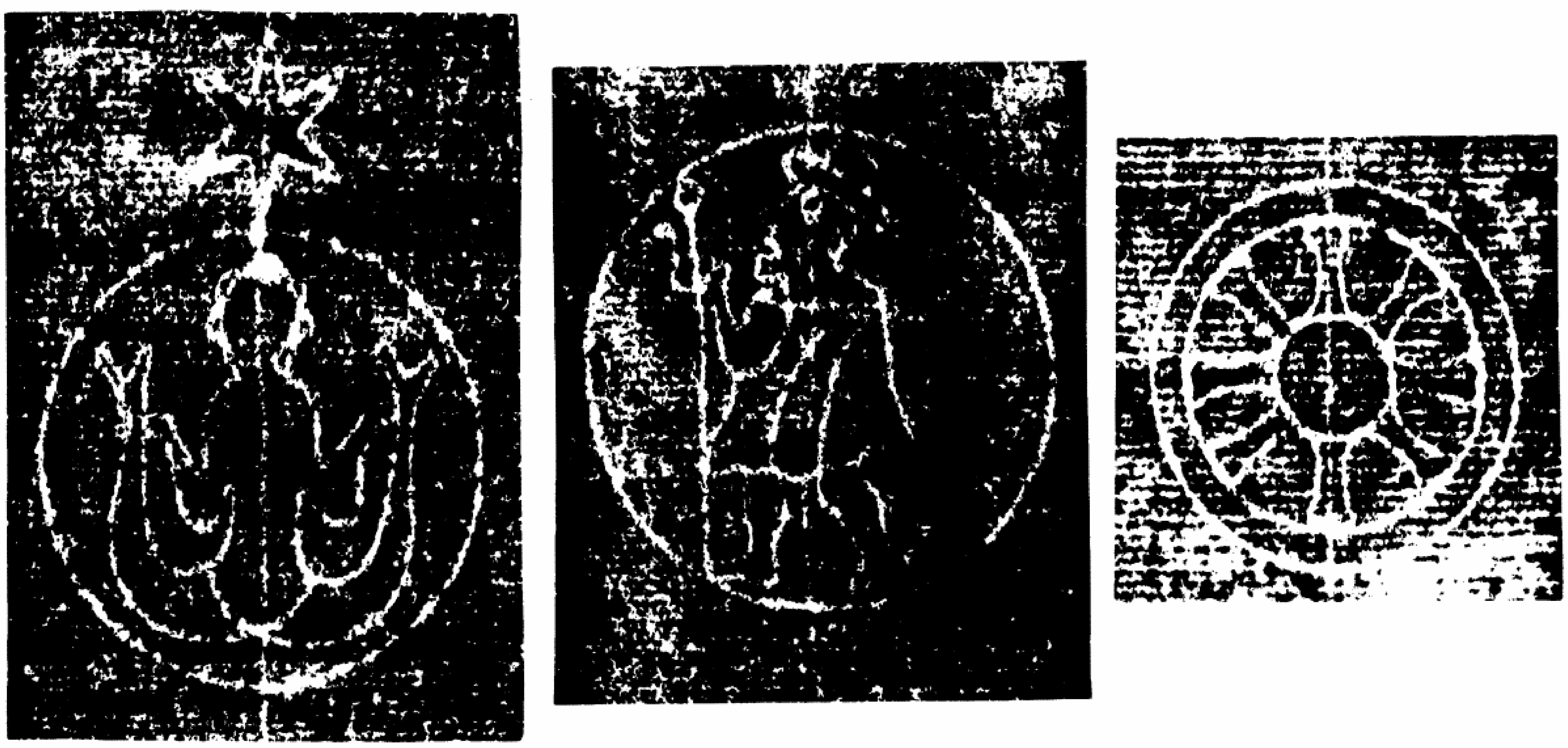

Fig. 6. Samples of watermarks used in the study, from left to right: Siren in circle with star, Shepherd, and Eight-spoked wheel. Author's radiographs.

No. of observations	Watermark name
28	8-spoked wheel (twin moulds)
16	Siren in circle with a star (twin moulds)
6	Crossed arrows
6	Ladder in circle
6	Ladder in shield
6	Shepherd A (version M)
7	Shepherd B (versions N & P: twin moulds)
4	Siren in circle without a star

Table 2: Categories of watermarks tested.

since been extensively used in a wide variety of disciplines, wherever the research design calls for categorical or nominal group construction, classification, verification or prediction, using other ratio variables.[10]

In format, the central product of DA is similar to that of multiple regression, in that DA also constructs an equation, known here as a 'discriminant function'. This has several independent 'discriminating variables' on the right of the equals sign, each weighted with an attached coefficient. However, DA differs from regression in that on the left of the equals sign the phenomenon being contributed to by the discriminating variables is not a dependent variable measured on a ratio scale, but a 'discriminant score', which indicates the position of a given case on the discriminant function. While regression analysis seeks to run a plane of best fit through a scatter of data points with the resulting equation of the plane being the best estimate of the average relationship between the variables in the system, DA operates in almost an opposite manner: the estimated discriminant function is actually the equation of the plane which best separates groups of cases of known membership within a statistical space defined by axes representing the discriminant variables. DA produces one function to separate two groups, two to separate three, and so on.

However, not every function in a multi-group system may be equally valuable, not every group may be readily distinguishable from every other group, not every case may be clearly a member of one particular group, and not every variable may be equally useful in making discriminations. Consequently, DA also produces a variety of summary diagnostic statistics to aid the researcher in making judgments about the results.

In summary, DA can thus: (1) sort out which variables of many candidates contribute significantly to successful discrimination between known groups of cases; (2) identify which individual variables are more important for this than others; (3) calculate the overall degree of success with which a separation can be achieved, and thus whether it makes sense, in terms of the variables available, to have cases distinguished by a given type of grouping; and (4) apply the relationships embodied in the discriminant function estimated from cases whose group membership is known, to other cases which are believed to be part of the same system but whose group membership is not known. DA is thus a particularly appropriate technique here, where the watermarks are the data observations measured categorically, the discriminating variables are various standardized chemical elements, and the goals are to see whether the watermark groups are distinct in terms of the chemical contents measured here and whether what appear to the eye to be slightly different watermark designs are, in fact, part of the same group or not.

When any two of the watermark groups were examined, they were invariably found to be quite distinct. For example, taking the two largest categories ('wheel' and 'siren in circle with star'), the significance of the discriminating function was 0.0161. Because this number is less than 0.05, this means that the difference between the two sets of watermarks is significant at the 95% level. This is illustrated most clearly by attempting to identify into which category a given watermark will fall knowing only the data of its chemical constituents, as in Table 3:

As a check that known twin watermarks do not relate to different types of paper, a test was

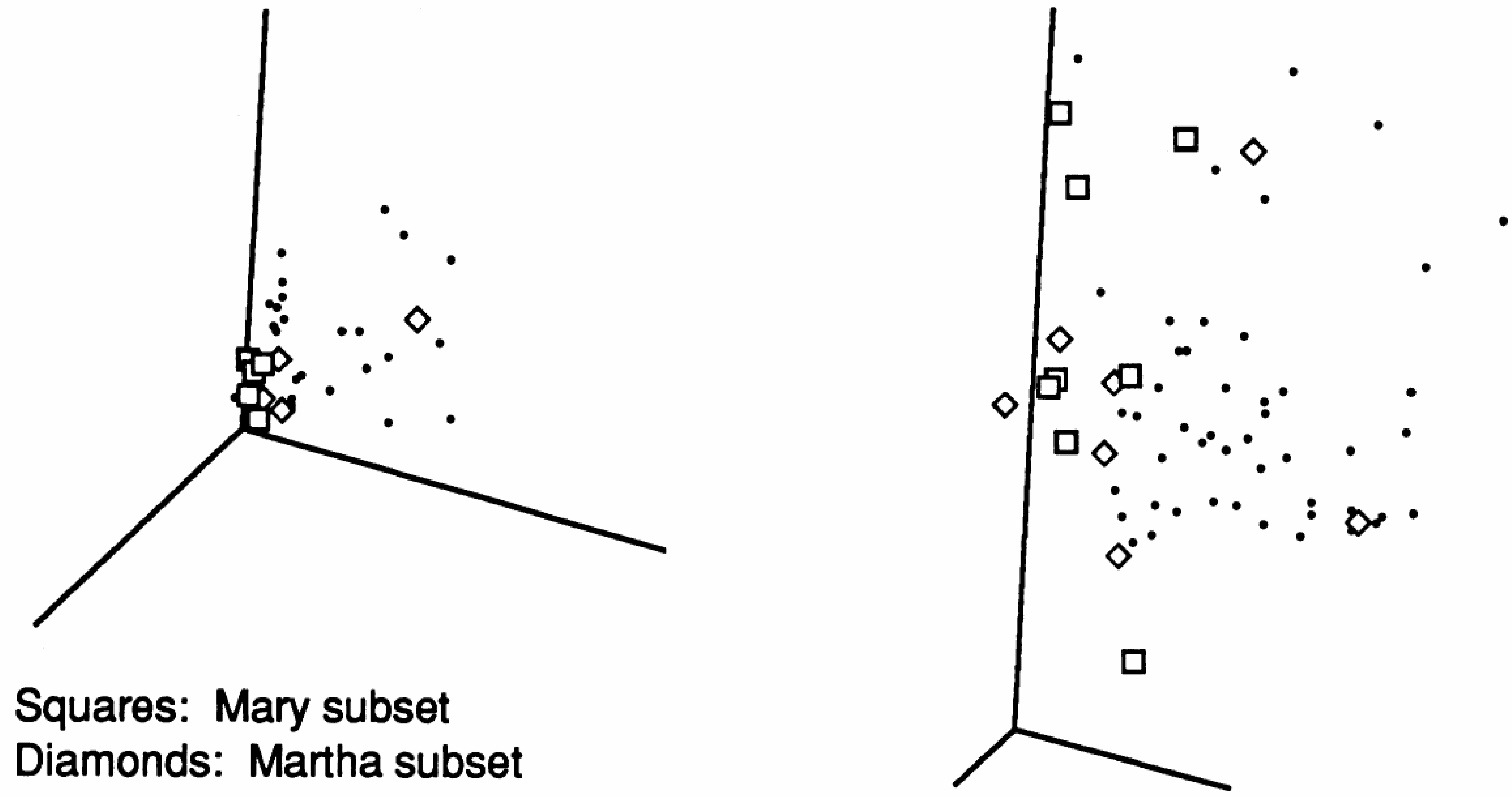

Fig. 7. Overlap of elements present in a statistical 'space' defined by axes representing the measured ratios to argon of iron, calcium, and potassium in the paper represented by several watermarks.

Watermark	Classified as Wheel	Classified as Siren
Wheel (N=28)	24 (85.7%)	4 (14.3%)
Siren (N=16)	2 (12.5%)	14 (87.5%)
Per cent of 'grouped' cases correctly classified = 86.36%		

Table 3: Prediction of classes into which 'wheel' or 'siren' watermarks will fall based only on knowledge of the chemical composition of the paper on which they are found.

run on the 'Martha' and 'Mary' versions of the siren in circle with star watermarks. From a previous study[11] these names were assigned and no other variants of this design are known to exist. The discriminant function was 0.1716, well above the 0.05 significance level, so the function probably does not discriminate significantly (at the 95% level) between the groups of paper bearing Martha and Mary watermarks. It can therefore be assumed that these watermarks are indeed twins used in tandem in similar vats of paper pulp. Fig. 7 shows the overlap of elements present in a statistical 'space' defined by axes representing the measured ratios to argon of iron, calcium, and potassium present in the paper:

The siren in circle and the crossed arrows watermarks were then compared, with the following results:

Watermark	Classified as Siren	Classified as Crossed Arrows
Crossed Arrows (N=6)	5 (83.3%)	1 (16.7%)
Siren (N=16)	1 (6.3%)	15 (93.85%)
Per cent of 'grouped' cases correctly classified = 90.91%		

Table 4: Prediction of categories into which 'crossed arrows' or 'siren' watermarks will fall based only on the knowledge of the chemical composition of the paper in which they are found.

The study then compared two ladder watermarks:

Likewise, the discriminating function between two types of shepherd watermark (here called "shepherd A" and "shepherd B") was significant at 0.67%, as shown in Table 6:

Watermark	Classified as Ladder in Circle	Classified as Ladder in Shield
Ladder in Circle (N=6)	5 (83.3%)	1 (16.7%)
Ladder in Shield (N=6)	0 (00.0%)	6 (100.0%)
Per cent of 'grouped' cases correctly classified = 91.67%		

Table 5: Prediction of classes into which 'ladder in circle' or 'ladder in shield' watermarks will fall based only on knowledge of the chemical composition of the paper in which they appear.

Watermark	Classified as shepherd A	Classified as shepherd B
Shepherd A (N=6)	5 (83.3%)	1 (16.7%)
Shepherd B (N=7)	0 (00.0%)	7 (100.0%)
Per cent of 'grouped' cases correctly classified = 92.31%		

Table 6: Prediction of classes into which 'shepherd A' or 'shepherd B' watermarks will fall based only on knowledge of the chemical composition of the paper in which they appear.

It should be noted that when more than two categories are analyzed at once, the attempt to classify the watermarks on the basis only of the chemical data becomes inconclusive, as shown in the following table:

Watermark	Cases correctly classified out of total	% cases correctly classified
Wheel	19/28	67.9%
Siren with star	3/17	17.6%
Crossed arrows	5/6	83.3%
Ladder in circle	4/6	66.7%
Ladder in shield	0/6	0%
Shepherd A	5/6	83.3%
Shepherd B	0/7	0%
'Grouped' cases correctly classified = 47.37% (only percentages correctly classified are shown)		

Table 7: Prediction of which categories paper with the watermarks tested will fall when analyzed at once.

Although the figures for 'crossed arrows' and 'shepherd A' still remain strong, in general the classification performance drops below 50%. We are perhaps encountering here limitations due to the nature of paper: the paper types are distinct, but as a whole the groups have fairly indistinct boundaries or occupy the same statistical domain. That is, the statistical domain of paper's chemical elements may be fairly small. Any two watermarks might well occupy different portions of that domain; but as the number of watermarks under analysis increases, so the domain 'fills up', and watermarks start to overlap. However, since the purpose of the analysis was to distinguish between paper groups on the basis of their watermarks, and not to automatically predict into which statistical domain a given group of measured elements will fall, this shortcoming is not severe. Future work will thus continue with this technique, systematically grouping the data so far gathered on sixteenth century Italian printed maps according to paper mould and gathering additional data from maps in the Novacco Collection.

Plates and Paper: the Next Stage

The evidence of paper needs to be related to that of the plates from which the map was printed. Statistics relating to chemical elements in paper are only meaningful when compared to a broader context of the artifacts. If the evidence of ink should prove to be more useful than it