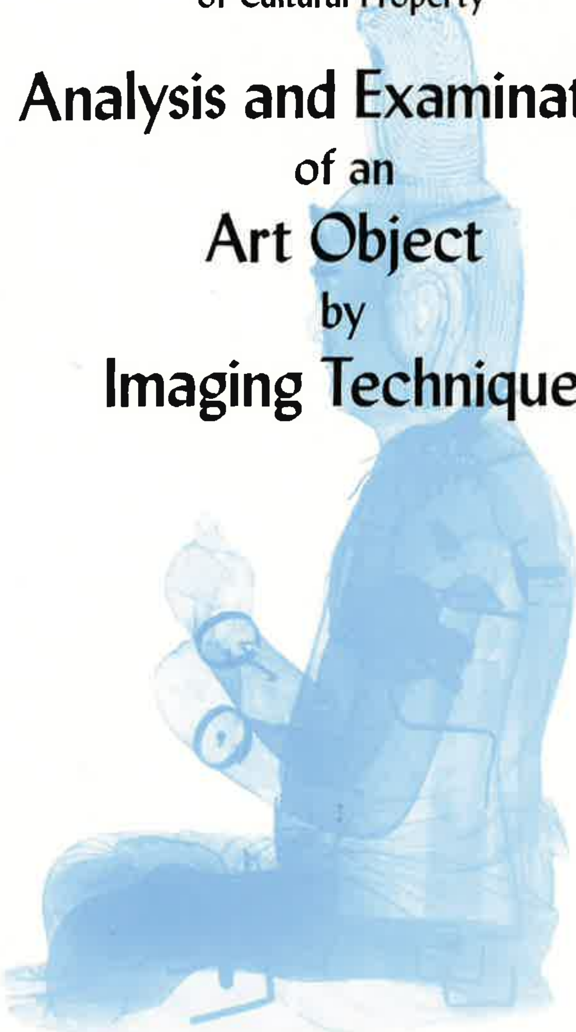
International Symposium on the Conservation and Restoration of Cultural Property

Analysis and Examination of an Art Object by Imaging Technique



Tokyo National Research Institute of Cultural Properties

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INTERNATIONAL SYMPOSIUM ON THE CONSERVATION AND RESTORATION OF CULTURAL PROPERTY
—ANALYSIS AND EXAMINATION OF AN ART OBJECT BY IMAGING TECHNIQUE—

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Analysis and Examination of an Art Object by Imaging Technique

Tokyo National Research Institute of Cultural Properties

Japan

THE STUDY OF DRAWINGS IN THE NEAR INFRARED

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SUMMARY

Even if several drawing media - used on one and the same drawing - sometimes show no visible "colour differences" and are therefore not distinguishable for the human eye, they might be differentiable in the adjacent NIR. In this range, infrared reflectography in combination with a 1000 nm long-pass filter turned out to be very useful, which is a new application of this well-known technique. Yet, reflectance spectroscopy in combination with multivariate statistical evaluation procedures offers far more possibilities for the differentiation of drawing media than infrared reflectography alone. Some results obtained here by reflectance spectroscopy will have influence for any future use of image processing systems in the investigation of drawings. And, our initial hypothesis, that various hands, i.e. ink wells or inks used on a drawing should be detectable in some way seems to have been proven correct.

1. Introduction

For eighty years art historians have debated about the so-called "Munich Rembrandt-Forgeries" (RENGER 1984). In the understanding of this series of drawings the number of hands turned out to be crucial. Simply said, this is synonymous with the number of inks used for each of them. Some scholars felt that the drawing was created by several artists, while others saw it as drawn by one artist alone. Their view was supported by stylistic observations, as well as by the "art historian's eye" which described the colour of the drawing media as homogeneous or as fluctuating between brown, red-brown, black and grey[1] (RENGER and BURMESTER 1985/86). However, no unanimous

[1] For example see ROSENBERG's 1959 review of BENESCH 1955/57 and citing WEGNER 1957.

and final decision could be reached as to the exact colour of the individual strokes. And, in general "the visual" seemed to support the scholars' hypotheses. This has been the starting point of this and previous publications.

For each of these drawings the major question we had to ask was whether scientific methods are better able to detect the different drawing media used than the human eye. In broader terms: Are there any scientific approaches in the investigation of drawings which complement the "visual" as the main source of art historians' information?

This paper is the third and final contribution to the problem of the "Munich Rembrandt-Forgeries". The first paper discusses in detail the scientific methods proposed and gives numerous examples of their application (BURMESTER and RENGER 1986). The second paper deals with the art historical background of the "Munich Rembrandt-Forgeries" and the consequences of the combined research (RENGER and BURMESTER 1985/86). The goal of this third publication is not merely to focus on the Munich Rembrandt-Apocrypha (as we now call them) but to present yet unpublished further methodical developments and an evaluation of the suggested methods for the analysis of drawings. The article discusses three applications and their results: The refined evaluation presented aims at being useful for any advanced application of image processing in the study of drawings. Due to spatial problems, after some basic thoughts we have to refer to other, as well as to our own publications[2].

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[2] For further information regarding the basics, the application, the difficulties of NIRA and for a phenomenological explanation of its results see BURMESTER and RENGER 1986, for the basics of infrared reflectography ASPEREN DE BOER 1969/70; for filter choice in infrared reflectography BURMESTER and RENGER 1986; for art history oriented discussion of the results RENGER and BURMESTER 1985/86. Finally, it should be mentioned that at the same time when these experiments have been conducted FLETCHER 1984 published a preliminary study of the use of infrared reflectography in the examination of works of art on paper.

2. Principal thoughts and analytical procedure

Drawings are generally executed on a light background, usually on paper. The composition itself uses various media, which in our case are mostly iron gall or carbonicious inks. It is common knowledge that these inks are made from a variety of recipes. The presumption that before the rise of industrial ink fabrication no two ink wells were alike justifies our hypothesis that drawings worked on by various artists could therefore show evidence of several types of ink.

What (scientific) possibilities are available to prove this? From the introduction we can deduce that the usual differentiation of drawing media relies on their actual colour. This differentiation can sometimes already by achieved in "the visible" range (VIS, 380 - 780 nm), which led to the first studies in the VIS on the "Munich Rembrandt-Forgeries" by reflectance spectroscopy (RENGER and PREUSSER 1983). However, the results in the VIS turned out to be far less conclusive than the range chosen in our work: the Near Infrared (NIR, 780 nm - 2500 nm) (BURMESTER and RENGER 1986). As we now know, a very clear differentiation of drawing media on a drawing in the NIR generally conditions a considerably weaker differentiability in the VIS. This also explains the art historical visual experiences and the results of the preliminary study mentioned above. Thus, a transition from the VIS to the NIR would be desirable.

Physiological experiments have shown that the human eye is a very bad detector in the NIR: Regardless of the type of illumination used, our power of vision in the NIR is diametrically opposed to the requirement to successfully differentiate drawing media. Aside from the eye, what physical detectors exist to extend "the visual" towards the NIR? Fig. 1 demonstrates the reflectance capability of drawing paper (P) as well as that of two different, for our eye however "identical(ly coloured)" drawing media (A and B) in relation to the wavelength of the energy irradiated. If one follows the spectra from lower to higher wavelengths one notices very low reflectance values in the ultraviolet (UV, below 380 nm), variable values in the VIS and broad reflectance bands in the NIR. The first area, which indicates a differentiability of A and B, is the VIS. The light paper reflects the majority of the energy irradiated (upper curve P). The drawing media absorb the light more readily (lower curve A, B) and therefore are seen as darker. The situation is more profitable in the NIR, although both curves representing drawing media narrow more or less the curve of paper towards the middle IR. However, all reflectance curves show rising higher values in the NIR when compared to the VIS. In addition, the resulting reflectance curves A and B are clearly differentiable in the NIR.

Therefore, we would expect that a NIR-sensitive system, as for example infrared reflectography, could help provide an answer to our questions. Within a broad NIR wavelength range ("a few hundred nm window") infrared reflectography transforms the energy reflected by the entire drawing or a section into a visible image. Theoretically, the experiment should yield different energy values for P, A and B, which are then transformed into three shades of grey (the "area" below the spectra in Fig. 1 within the window mentioned). It is decisive that, through the choice of an appropriate long-pass filter (here Schott glass filter RG 1000) the image of some drawing media (in this case A) becomes identical to that of the paper, thus making the strokes executed in A invisible (BURMESTER AND RENGER 1986).

Another option is to make point-by-point measurements of minute areas of the drawing using reflectance spectroscopy. This is done under wavelength dispersive detection of the reflected energy: The irradiated wavelength range is very small ("1 nm window") but changes over time in a defined range. Thus, a series of reflectance values is observed resulting in a reflectance spectrum (Fig. 1). These spectra demand scrutinious evaluation, since their information yield no immediately recognizable image for the human eye. For this reason it initially appeared to us that the use of reflectance spectroscopy in the NIR (NIRA) was inferior to that of infrared reflectography and thus may have been perceived by our readers as visually underrepresented in our earlier publications.

3. Applications and results

In regard to the differentiability of its drawing media, the

"Study of Two Apostles" (Staatliche Graphische Sammlung Munich, W1146, Photo 1) has proven to be an easy case for NIRA as well as for infrared reflectography (Photo 2). The latter yields a satisfying answer to the question of which parts were created later by a second hand in the same tone as the original drawing, namely almost all.

However, not every line drawn could be categorized conclusively on the basis of infrared reflectography. With the help of NIRA this was made possible, since it permits a point-by-point classification of the drawing media. A selection of the digitized reflectance spectra is shown in Fig. 2.

Initially, it seemed to be sufficient to combine all reflectance spectra collected in a simple diagram which represents the slope of the spectra as well as their absolute position (Fig. 3). This graph displays even the thickness of the ink application: The points to be found at the end of the cluster (low reflectance values) - opposite the area where the points of the paper are plotted (high reflectance values) - are correlated with a dark, heavy application of drawing media. Based on previous experiences, it seemed to be advisable to use multivariate statistics (COOLEY and LOHNES 1971) for this and other applications. For the multivariate evaluation the reflectance spectra were digitized at 50 nm intervals (750 nm, 800 nm, ..., 1600 nm) and analyzed by means of the SPSS/PC+ advanced statistics software package.

It was not surprising that there was a high correlation between adjacent wavelengths. Consequently, the first factor of the principal component analysis already shows a variance of 90%, whereas the second only 9.7%[3]. A plot of the factors (Fig. 4) reflects the best possible separation of points at optimum visibility.

Those points not yet grouped can easily be described as either A or B. Thus a safe "classification" can be made. By the way, a cluster analysis can double check whether any classifications derived from visual analysis, from stylistically critical arguments or from principal component analysis are correct.

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[3] Notice that only 0.3% of the information out of a total of 80 reflectance spectra with 18 data points each is lost.

This is done objectively and solely on the basis of the experimental results.

The next example, "Group of Figures" (Staatliche Graphische Sammlung Munich, signed "Rembran", W 1181, Photo 3), poses greater problems: the eye recognizes only one drawing medium and unfortunately the infrared reflectogram (Photo 4) lacks any contrast. In addition, it appears that one and the same grey tone on the infrared reflectogram can be correlated on the one hand to a heavy, and on the other hand to a very thin application of ink on the original drawing itself. As we know from NIRA, this is due again to the use of two drawing media A and B. Based on the infrared reflectogram alone we can therefore not conclusively categorize the values into either A or B.

Fig. 5 shows a principal component representation of all spectra recorded. The variables are highly correlated: Fig. 6 shows the loadings of the two factors used whereby the total variance of factor 1 is 78.5% and that of factor 2 20.4%[4]. On this basis, final decisions could be made for special parts of the drawing under discussion. For instance, the point 1616 and 1622 (see Fig. 5) can be ascribed to A (as we know, the drawing medium of the original). However, points 199 and 1624 can be classified as B (the drawing medium of later additions). No evidence is given for points 890, 891 and 892 which are grouped to A (890, 892) or to B (891) by a cluster analysis (two principal components, Ward's method). It thus supports the results of a discriminant analysis (Mahalanobis distance) regarding the classification probabilities which read 99% to A for 890, 53% to B for 891, and 95% to A for 892. All these situations can be allocated exactly to those strokes where different drawing media were drawn on top of each other.

By the way, the signature is classified by NIRA as B, which can scarcely be seen on the infrared reflectogram (Photo 4). However, these signatures are important in the series of art historical arguments, since signatures on Rembrandt drawings are hardly ever present. Their appearance makes the drawings themselves dubious: They are therefore generally discussed as

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[4] The minimum value of the correlation coefficient is 0.27 (750 nm versus 1450 nm). It is clearly lower than for the "Study of Two Apostles" with 0.51 (750 nm versus 1400 nm).

complete fakes or drawings with later additions. Here the signature, along with all other lines drawn in B, is considered a later addition (from the 18th century, see RENGER and BURMESTER 1985/86). Numerous stylistically critical arguments support this conclusion.

In our context a situation of special interest arises with a drawing attributed to a Maes-follower (WEGNER 1973). It is important to recognize that the analysis of the drawing and a discovery of three drawing media A, B, and C have only been possible when all the techniques mentioned above have been combined. Until now, the eye could not discern the use of three drawing media. Even the simple fact that the "Woman with Child" (Staatliche Graphische Sammlung Munich, W 762, Photo 5) was altered had been overlooked. Evidently, an original conception was discarded and the central figure was placed into a new piece of paper.

Compared with the original (Photo 5) the infrared reflectogram (Photo 6) only shows strokes which appear less or more strongly weakened. The execution of the least weakened lines reminds one of the duct of the additions observed on the two former examples (dark strokes in Photo 2 and 4). In close comparison with the reflectogram the results of NIRA, here shown as a principal component plot in Fig. 7, prove with certainty that two additional drawing media (A and B) are detectable which are again revised later with C.

A discriminant analysis provides further help by categorizing the individual sections, such as the head of the woman on the right, into specific drawing media for which no definite decision could be made. Sections where two or more drawing media were applied on top of one another can also be differentiated in this manner. Thus, NIRA recognizes that, for example, the shoulder projecting toward us of the woman on the right is originally executed in B and then revised in C.

All categorizations can be double checked with the help of the cluster analysis of the NIRA data for "Woman with Child" (two principal components, Ward's method). The results reflect the discussion above: C is clearly grouped separately from A, light points of A fall into the same cluster as the paper and thus find association to B, which generally has a lighter application than C.

Based on the observations from the three applications shown above, which summarize the numerous inspected Munich Rembrandt-Apocrypha, we have arrived at the following conclusions:

1. Even if drawing media show no visible "colour differences" and are therefore not distinguishable for the eye, they sometimes can be differentiated in the adjacent NIR. This could be proved by our work on European drawings and manuscripts, which frequently used liquid drawing media such as iron gall inks and carbonicious inks. Our initial hypothesis that various hands, or better yet, various ink wells, should be detectable on the same drawing therefore seems to have been proven correct. Using the Munich Rembrandt-Apocrypha, it can be shown that art historians now have access to additional scientific procedures which support their eye.
2. The use of a 1000 nm long-pass filter for infrared reflectography seems to be very effective. In combination with this filter infrared reflectography permits a quick and sure identification, especially those drawn with carbonicious inks.
3. However, NIRA offers even more possibilities for the differentiation of drawing media than infrared reflectography. Its final result is strongly supported by a detailed multivariate statistical evaluation as demonstrated here.
4. All statements made regarding the differentiability of drawing media are only valid within one and the same drawing, which does not pose any problem for the art historian. The procedures used here do not permit the finding of one and the same ink well, which generally also means the same artist, on different drawings. Furthermore, both procedures proposed can not characterize the drawing media used according to their exact chemical nature.

4. Discussion

It is not the place to discuss the art historical consequences of our work again (RENGER and BURMESTER 1985/86). Instead, we will focus on various methodical aspects.

After its main use to detect underdrawings covered by paintlayers and varnishes this approach is a considerable extension of the applicability of infrared reflectography. Here, this technique reveals an "hidden" image on the drawings under investigation. Although visible to the scholars' eye as an ink application on paper the main information is hidden in the NIR and is made visible by the camera. This is a new and advanced application of infrared reflectography. As shown in the first example "Study of Two Apostles," the use of a 1000 nm long-pass filter is very successful. This could be confirmed by our research on many drawings of the Munich Rembrandt-Apocrypha. Yet our last example, "Woman with Child", revealed the occasional and mostly underestimated difficulty of understanding these infrared reflectograms.

With respect to our results by infrared reflectography, NIRA in the manner executed here, still seems to be the superior method. It is possible not only to differentiate drawing media, but also to classify strokes on a drawing which come from the same ink well with a high degree of certainty. With infrared reflectography this can only be partially achieved.

However, a point-by-point measurement by NIRA requires much more time than an application of infrared reflectography, reaching a factor of hundred or more when considering a complex drawing. In addition, the final results never cover every single stroke of the drawing. Aside from these drawbacks, there is also the time consuming evaluation process, which demands a high degree of attention and exactitude on the part of the analyst. For example, after numerous experiments in which we tried to get a grasp of "Woman with Child", we learned that the unerring key to understanding is the NIRA in combination with principal component analysis. But, every reflectance spectrum had to be discussed in detail. It turned out that a bivariate representation (as in Fig. 3) lead to a great number of erroneous categorizations. Therefore, the multivariate statistical evaluation should not be abandoned.

With the help of principal component analysis an optimum classification of the drawing media used can be achieved rather elegantly. Furthermore, in some cases discriminant analysis gives us an idea as to which amount the various overlapping drawing media contribute to the final reflectance spectrum.

However, discriminant analysis, as well as the cluster analysis mentioned, which can objectively show a "classification" based on the principal component analysis, are only considered additions. In general, a clustering by eye on the basis of the principal component analysis in combination (!) with the reflectogram seems to be superior to any automatic procedure.

In the case where several iron gall inks are present on one and the same drawing, it turned out that an evaluation of the reflectance spectra by bivariate techniques is insufficient. Moreover, until now only NIRA permits to differentiate these iron gall inks, whereas infrared reflectography is non-applicable.

After having evaluated a great number of these Munich Rembrandt-Apocrypha, dozens of infrared reflectograms and about two thousand reflectance spectra, the question was raised as to how infrared reflectography could be improved to yield the same information as NIRA.

The limited capabilities of infrared reflectography can again be shown with the drawing "Woman with Child": it is obvious that in the range of 1150 nm - 1600 nm (this range is partially the same as that used for infrared reflectography with the 1000 nm long-pass filter) a clear visual differentiation between A and B can not be expected (see principal component representation in Fig. 8). Only after extending the range to include lower wavelengths we do get an improved differentiability (Fig. 7). Thus, the distinguishing information is to be found at lower wavelengths (Fig. 9). This has to be taken into consideration in future applications of infrared reflectography.

Major improvements should be expected by the use of image processing systems. In a first attempt, we tried to show the examples presented here free of all later additions (B resp. C). This had to be done with photographic reproductions of the original drawings and the infrared reflectogram. This attempt can be considered partially successful (Photo 7 to 9).

Obviously, the success of our image processing experiments was limited by the use of reproductions instead of the primary information, the originals themselves. We hope to present processed images of far higher quality on the base of high resolution digital images of the original "Munich Rembrandt-Apocrypha" in the near future.

Acknowledgments

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Figures and Photographs

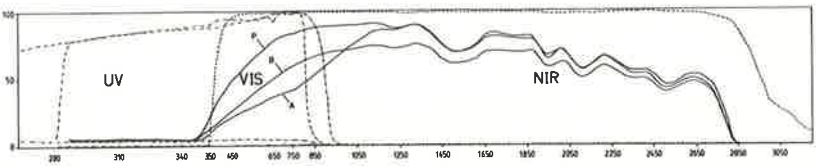

Fig. 1 Typical diffuse reflectance spectra of paper (P) and two drawing media (A and B). The diagram shows relative reflectance values [%] on the ordinate versus the wavelength [nm] on the abscissa. For further explanations see BURMESTER and RENGER 1986.

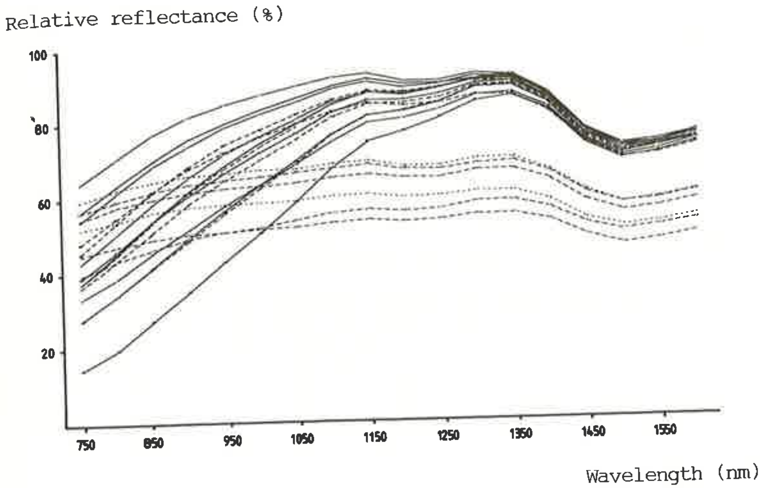

Fig. 2 Digitized reflectance spectra of the "Study of Two Apostles"

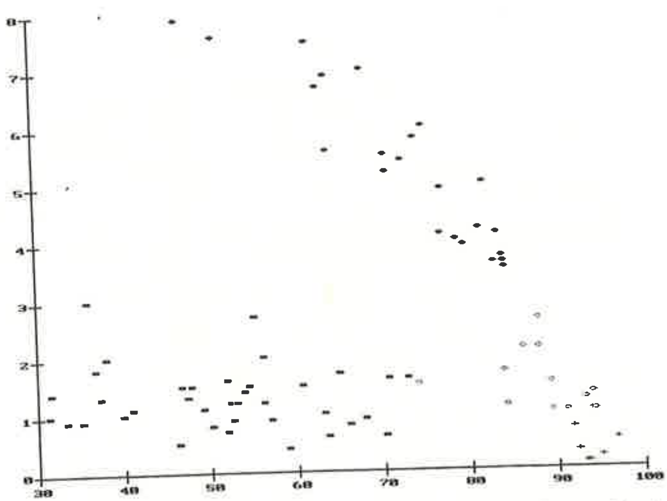

Fig. 3 "Study of Two Apostles": Difference of the reflectance values at 1000 nm and 950 nm ("the slope of the reflectance curve") [%] versus the reflectance value at 1000 nm ("its position") [%] for paper (+), drawing media A (◆) and B (▬) as well as unclassified (◇)

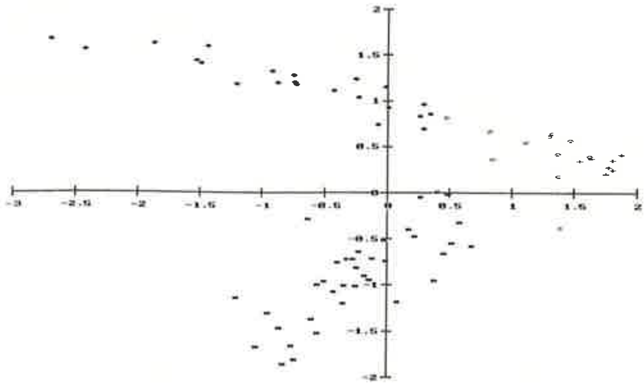

Fig. 4 Principal component plot for "Study of Two Apostles" with factor 1 as ordinate and factor 2 as abscissa
All measured wavelengths included; for symbols see Fig. 3

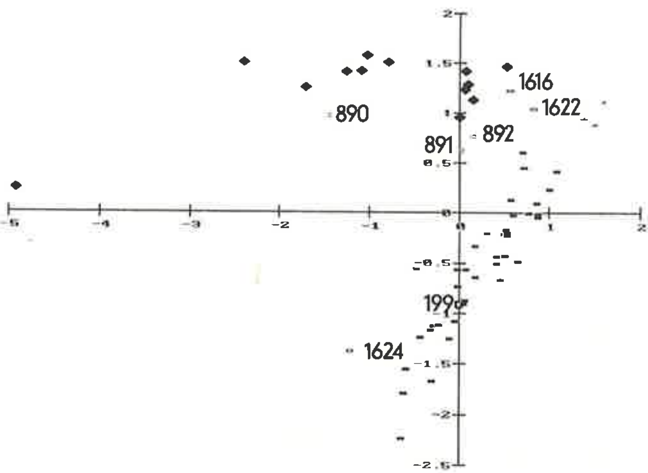

Fig. 5 Principal component plot for "Group of Figures"
For further explanation see Fig. 4; symbols used as in Fig. 3
For special labelled points see text and Photo 3

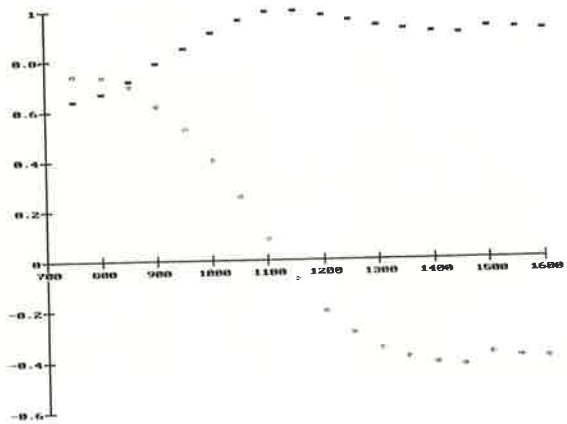

Fig. 6 "Group of Figures": Factor loadings of factor 1 (▬) and factor 2 (◇) for all wavelengths measured [nm]

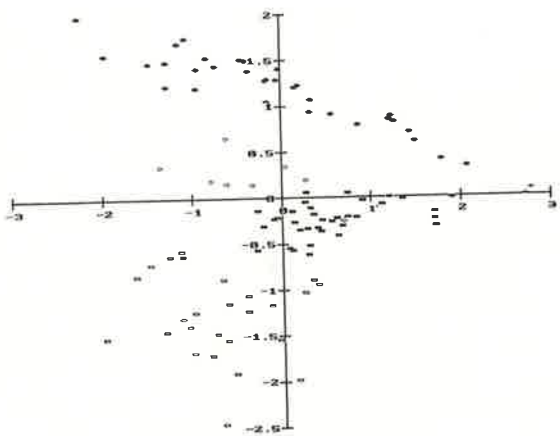

Fig. 7 Principal component plot for "Woman with Child"
All measured wavelengths from 750 nm up to 1600 nm included
For further explanation see Fig. 4; symbols as in Fig. 3; drawing medium C (▭)

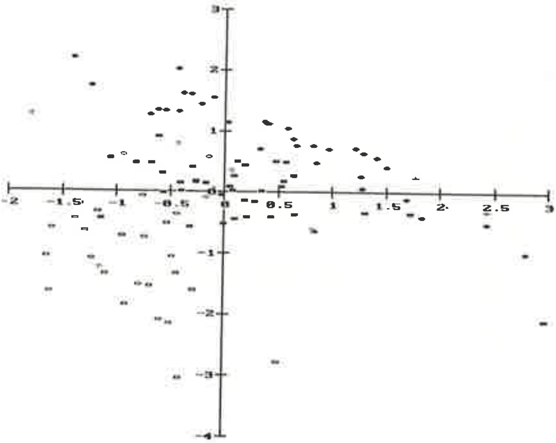

Fig. 8 As Fig. 7, wavelengths between 1150 nm and 1600 nm included

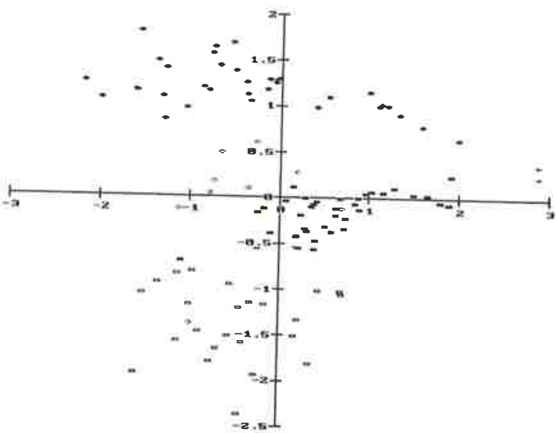

Fig. 9 As Fig. 7, wavelengths between 750 nm and 900 nm included

Photo 1 (left) "Study of Two Apostles", Staatliche Graphische Sammlung, Munich (WEGNER 1973, W1146)

Photo 2 (right) Infrared reflectogram of the "Study of Two Apostles", Grundig TV camera FA 76S with Hamamatsu N 241-06 tube, Schott RG 1000 long-pass glass filter, monitor Grundig BG 12 (875 lines) on Ilford FP4 b/w film

Photo 3 "Group of Figures", Staatliche Graphische Sammlung, Munich (WEGNER 1973, W1181)

Photo 4 Infrared reflectogram of the "Group of Figures"

Photo 5 "Woman with Child", Staatliche Graphische Sammlung, Munich (WEGNER 1973, W762)

Photo 6 Infrared reflectogram of the "Woman with Child"

Photo 7 Attempt to eliminate the additions from "Woman with Child" by digital image processing (KONTRON IPS) after interactive Helmert transformation (photograph by courtesy of B. Kopainsky)

Photo 8 Attempt to eliminate the additions from "Group of Figures" by digital image processing (KONTRON IPS) after interactive Helmert transformation (photograph by courtesy of B. Kopainsky)

Photo 9 Attempt to eliminate the additions from "Study of Two Apostles" by digital image processing (KONTRON IPS) after interactive Helmert transformation (photograph by courtesy of B. Kopainsky)

DISCUSSION

LAHANIER: What is the area that you analyzed with the spectrometer?

BURMESTER: It's 1 x 2 mm. It's very small. The spots could be made smaller, but then you get a problem of sensitivity. On the other hand, if you enlarge this spot, you get too much unnecessary information. So it's something in the middle.

MILAZZO: You are especially interested in the reflectance properties of inks to distinguish them. Then your infrared reflectography of drawings means something different from usual reflectography.

BURMESTER: Yes, you're right. It's in some way a new application, but I think that it's a very useful method and we try to use it wherever possible.

Someone asked me what is the nature of the inks we are looking at. It's very hard to answer, because we have not been allowed to take samples.

MILAZZO: Have you used X-ray fluorescence to characterize different inks?

BURMESTER: Yes, we have. But unfortunately, we looked at inks which are very, very similar and so we were not able to see too much difference with X-ray fluorescence.

SRAMEK: From what I know about IR spectroscopy, the convenient region is just between 400 and 2000 nm. Since the vibrational and rotational stages of molecules are so similar in this region, I don't think that it will be much connected with the nature of the compounds used. I would hesitate a little bit to say that everything is only a matter of different types of pigment. And I would focus more on the technology that was used in this drawing, on the thickness of the layer and how the ink was, for instance, mixed together.

BURMESTER: Yes. We are not able to say that this ink is composed of *x* or *y* only from the NIR spectrum. So I was very, very careful to say what the ink is in my presentation.