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IMAGE PROCESSING IN MICROWEAR STUDIES ON FLINT ARTIFACTS

The first interest on functional analysis of the stone tools, analyzing the use-wear traces, is most probably represented by the pioneering work of S. Semenov, more than thirty years ago (SEMENOV 1964), practically unknow for long time in the Western World. Several years later, a new interest aroused on the subject, both regarding the so-called "macrowear" traces (impact scars, striations, etc.) according to a line of research put forward by ODELL (1980), where practically only low magnification microscopes (eventually with additional SEM studies) are needed, and the "microwear" traces, first suggested by L.H. KEELEY (1980) and his followers (see, for instance, ANDERSON GERFAUD 1981; MOSS 1983), where high magnification microscopes are needed in order to study the various "polishes" produced on the used part of the artifact.

It is quite obvious that a a preminent role in this studies is consitued by experimental work: only when we have a reasonable amount of experimental data with experiments performed on various materials (wood, bone, antler, hide, meat, etc.), we can dispose of a kind of "data-base" for the interpretation of the archaeological record.

Needles to say, there is still an important factor that has to be taken into account: the chemical study of the process of formation of use wear polishes and, even more important, the possible effects of post-depositional alterations on the prehistoric flint material (see, for instance, LEVI-SALA 1993; YAMADA 1993, and the literature quoted in these papers).

The main focus of the present paper deals instead with the experimental part of the microwear studies, and in particular with the attempts of quantifying it. The need of quantification is easily understandable, because most of the analysis consists in the interpretation of the various types of polishes present on the working edge(s) of the artifact contained in an image derived from observations of the samples with a high magnification (up to 500 X) microscope.

Is thus quite natural that the simple analysis "by eye" of these pictures may introduce a large degree of subjectivity in the results: "blind tests" were often done in order to assess a better "reliability" of the analysis.

More quantitative procedures of image processing have therefore been introduced in order to avoid these "blind tests", which are obviously time consuming.

The first approach was of the standard "pattern recognition" type, with statistical applications to the images processed. Apparently, the first attempts in this direction (GRACE *et al.* 1985; GRACE 1989) failed to give reasonable answers, so that a second line of approach was tried: the use of Artificial Intelligence and expert systems (GRACE 1993; DRIES 1994).

In my opinion, the line of research more "pattern recognition" oriented was too quickly abandoned, and I may also add the the main drawback of the use of expert systems id the scarce flexibility of such systems, which obey strictly to rules essentially empirical and thus largely depending on the "teacher" and mostly variable through time.

In the present paper I will instead illustrate some results, which seem encouraging, obtained using the traditional "pattern recognition" statistical analysis.

The usual parameters derived from the microwear studies are of various type: the length of the polish along the worked edge of the tool, the width and, more important, its textural properties. As it was the case in the analysis done by R. Grace and collaborators (GRACE *et al.* 1985), we are here interested in quantifying the texture of the polish. The basic steps of the analysis are the following:

a) Digitization of the relevant portion of the image to be analyzed.
b) Transformation of the digitized image to a grey tone matrix.
c) Processing of this grey tone spatial matrix and computation of the features to be used in the statistical evaluation.
d) Statistical analysis of the features and discussion of the results.

The computation of the features is derived by a work published more than twenty years ago (HARALICK *et al.* 1973): the analysis done by R. Grace and collaborators (GRACE *et al.* 1985) was limited to the first three steps of the procedure outlined above, calculating only two of the statistics defined by HARALICK *et al.* (1973), called CON and ASM.

In Fig. 1 we can see a scatterplot between these two statistics for a series of experimental samples: actually the quanties plotted are the difference between the used and the unused sample both for CON and ASM statistics.

As can be seen, the unused samples cluster essentially around the origin, as expected, but the umpleasant result is that, apart two "outlyers" (open triangles) in the middle of the plot), representing two samples which worked hide, there is no clear distinction between samples which were experimented on wood, antler, plant or hide.

This negative result led R. Grace and collaborators to reject any further attempt of statistical pattern recognition analysis on the microwear traces and to shift to expert systems (GRACE 1993).

Actually, we have recently examined more carefully the paper of R. Haralick and collaborators (HARALICK *et al.* 1973), and we found that the number of features describing textural properties is *much larger* than the simple two, ASM and CON, employed by R. Grace and collaborators: in fact, there are 14 features defined for the analysis (HARALICK *et al.* 1973, 619).

We have thus tried to re-examine the possibilities of a statistical analysis

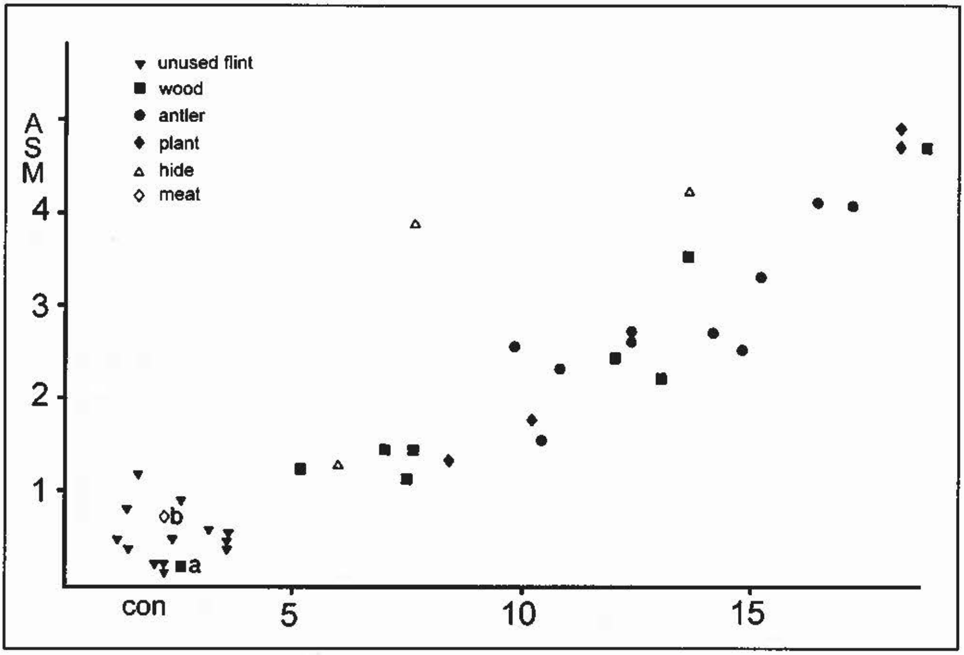


Fig. 1 – Scatterplot between the CON and ASM statistics for used and unused artifacts. For further explanations see the text (from GRACE *et al.* 1985).

on experimental microwear traces, considering 11 of these features. This work, done at the Faculty of Science of the University of Rome «La Sapienza» is still in progress, and the the research team is composed, according to the different phases and stages by C. Lemorini and P. Rossetti (experimentation and microwear microscope analysis, recorded on a standard CD), image processing and creation of the grey tone spatial matrixes (S. Morganti), processing of these matrixes and computation of the texture features (L. Zanello), statistical (univariate and multivariate) analysis of the features (A. Bietti).

In the present paper I will present only some preliminary results on a limited sample (BIETTI *et al.* 1994): work on a much larger series of samples is in progress.

Let us now define the features (HARALICK *et al.* 1973, 619) employed in our analysis:

$$F1 = \sum_{i,j} (p_{ij})^2 \qquad \text{(Angular Second Moment)}$$

$$F2 = \sum_{n=0}^{N_g-1} n^2 \Big[\sum_{\substack{i,j=1 \\ |i-j|=n}}^{N_g} p_{ij}\Big] \qquad \text{(Contrast)}$$

$$F3 = \frac{\sum_{i,j} (ij)p_{ij} - \mu_x \mu_y}{\sigma_x \sigma_y}$$ (Correlation)

$$F4 = \sum_{i,j} (i - \mu)^2 p_{ij}$$ (Sum of Squares Variance)

$$F5 = \sum_{i,j} \frac{p_{ij}}{1 + (i - j)^2}$$ (Inverse Difference Moment)

$$F6 = \sum_{i=2}^{2N_g} i \, p_{x+y}(i)$$ (Sum Average)

$$F7 = \sum_{i=2}^{2N_g} (i - F_6)^2 p_{x+y}(i)$$ (Sum Variance)

$$F8 = \sum_{i=2}^{2N_g} p_{x+y}(i) \log [p_{x+y}(i)]$$ (Sum Entropy)

$$F9 = - \sum_{i,j} p_{ij} \log p_{ij}$$ (Entropy)

$F10 =$ variance of p_{x-y} (Difference Variance)

$$F11 = - \sum_{i=0}^{N_{g-1}} p_{x-y}(i) \log [p_{x-y}(i)]$$ (Difference Entropy)

where

N_g is the number of distinct grey levels

P_{ij} is the frequency of occurence of levels i,j as neighbors for distance d and fixed direction (see Fig. 2)

R is a normalizing constant, i.e. the total number of pairs i,j found for distance d and fixed direction (see Fig. 2)

$p_{ij} = P_{ij} / R$ is the normalized frequency matrix

$$p_x(i) = \sum_{j=i}^{N_g} p_{ij}$$ is the i-th value of the marginal probability matrix

$$p_y(j) = \sum_{j=i}^{N_g} p_{ij}$$ the same for the j-th value

$$p_{x+y}(k) = \sum_{i,j=1}^{N_g} p_{ij} \qquad i + j = k \qquad k = 2, 3, ..., N_g$$

$$p_{x-y}(k) = \sum_{i,j=1}^{N_g} p_{ij} \qquad k = |i - j| \qquad k = 0, 1, ..., N_g - 1$$

μ_x is the mean of p_x distribution $= \sum_i i\, p_x(i)$

μ_y is the mean of p_y distribution $= \sum_j i\, p_y(j)$

μ is the smean of p distribution $= \sum_{i,j} i\, p_x(i)_i$

and σ_x, σ_y the standard deviations.

The distances d (1, 2, etc.) of the nearest neighbor from the pixel i,j are illustrated in Fig. 2. In the same figure one can see the four *directions* (quoted in the formulas) for the computation of the features: the central row and column and the two diagonals (see HARALICK *et al.* 1973, Fig. 1).

As a result, the number of the 11 features outlined above (the other three features difined in the work of R. Haralick and collaborators have been not considered in the present paper only for computation difficulties), is doubled: we have thus the averages (FA1, FA2,..etc.) and the ranges (FR1, FR2, ...etc.) over the four directions.

We have thus a much larger set of parameters in comparison with the analysis by R. Grace and collaboratorators (incidentally, it is clear that the

2		2		2
	1	1	1	
2	1	i,j	1	2
	1	1	1	
2		2		2

Fig. 2 – The nearest neighbors of pixel i,j for d = 1 and d = 2 (from BIETTI *et al.* 1994)

ASM statistics in Fig. 1 is the Angular Second Moment (F1 in our formulas) and CON is most probably the Contrast (F2 defined above)).

In our preliminary analysis the experimental sample consisted of 15 flint tools: nine of them wood working and the other six having worked hide.

The statistical analysis, after the computation of the 22 parameters defined above, consisted first in a simple univariate T-test at a 98% confidence level (a rather "severe" limit) in order to choose the diagnostic features for distinguishing between the two classes of artifacts. For d = 1 (we recall that d is the distance between the pixels (see Fig. 2)) the T-test gave very sharp results: only the features FA3 and FR3, representing the correlation (see the formulas above) are diagnostic. A further analysis that has been applied is the stepwise linear discriminant analysis, which, employing analyses of multiple and partial correlation, ranks the diagnostic features in a descending order of importance.

As a result, 13 features were selected: FR3, FA2, FR5, FR9, FR7, FA3, FR8, FR4, FR2, FR6, FA5, FR1, FR11. Needless to say, the features FA3 and FR3 were already selected by the T-test.

It is interesting to note that while the feature F2, (probably the CON of Grace *et al.* 1985), both in average and range, is diagnostic at a fairly good level of ranking, the angular second moment, F1 (ASM in Grace's paper) is one of the last features sorted, and only by its range.

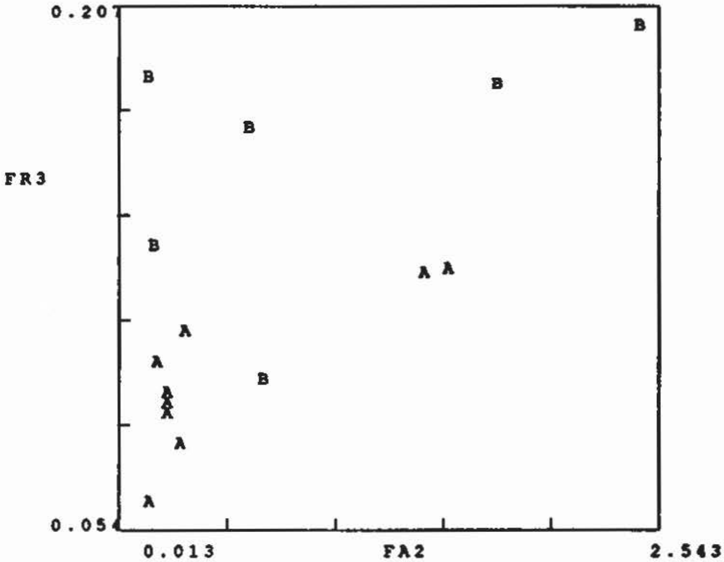
In Fig. 3a one can see the scatterplot of the data (for d = 1) between the features FR3 and FA2 and in Fig. 3b the same for the features FR3 and FA3: one can see clearly that the samples hide working (labelled B) are quite separated from the ones wood working (labelled A), with the exception of one hide working outlier, which is consistently mixed with the A' s: this specimen represents a hide working tool *but* at 400 X magnification (the other specimens ar all at 200 X magnification): is thus quite reasonable that it falls out from his class.

Principal component analysis has also been applied, but the results are rather poor (see Bietti *et al.* 1994, Fig. 4a and 4b), because of the limited number of samples and for the strong correlation between some features.

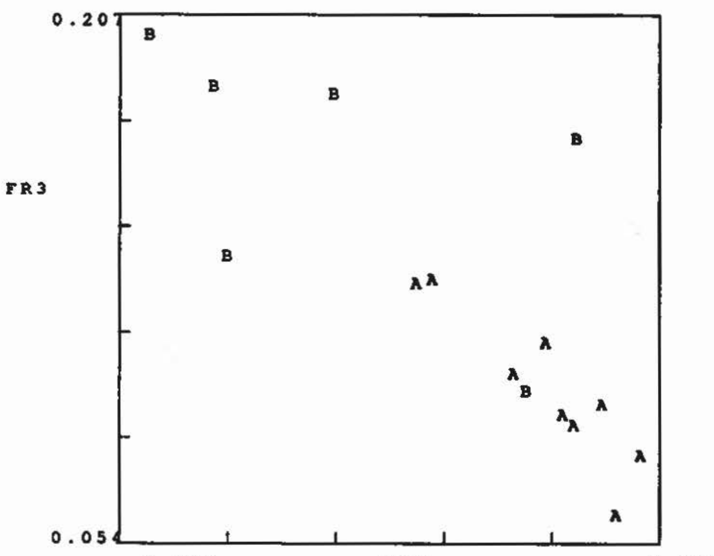
Moving now to the analysis with d = 2, the resolution between the two classes is much poorer: the T - test selects only one diagnostic feature, FA3, and the stepwise linear discriminant analysis again 13 features, but only 7 are in common with the analysis with d = 1.

In Fig. 4a we can see, for instance, the scatterplot between the features FA3 and FA1: the separation between the two classes is still reasonable (always with the some outlier of the hide working class mixed with the wood working specimens), but the scatterplot between the features FA3 anf FR4 (Fig. 4b) shows a rather bad resolution: is interesting to see that the scatterplot between the same two features in the case d = 1 (Fig. 5) gives a much better resolution.

As a conclusion, this preliminary analysis on a very limited sample gives, in my opinion, very incouraging results, and, at the present time, we are doing new analyses on a sample of about 100 experimental tools.

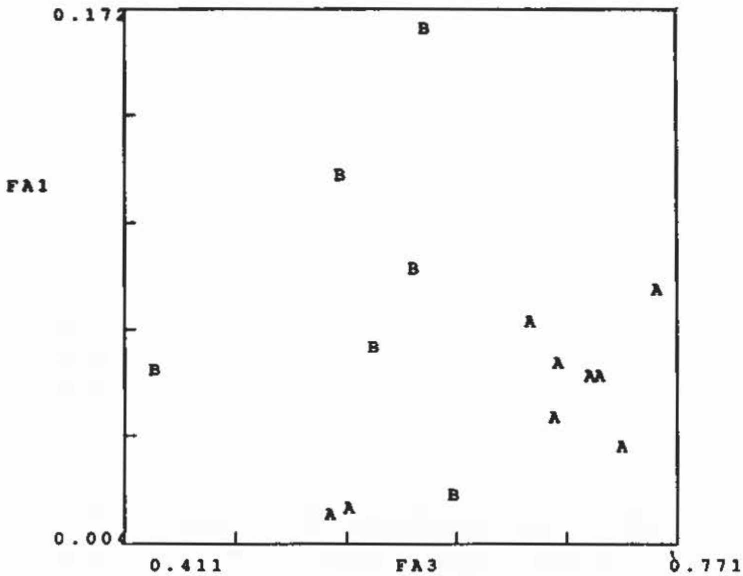


a

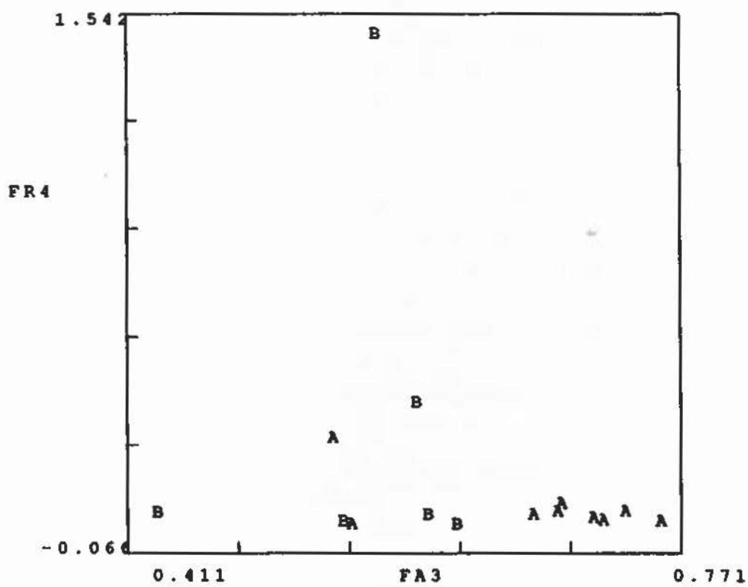


b

Fig. 3 – a) Scatterplot between the features FA2 and FR3 for artefacts wood working (a) and hide working (b) and d = 1; b) the same for the features FA3 and FR3 (from Bietti *et al.* 1994).



a



b

Fig. 4 – Same as in Fig. 3 for d = 2 and a) FA3 and FA1; b) FA3 and FR4 (from BIETTI *et al.* 1994).

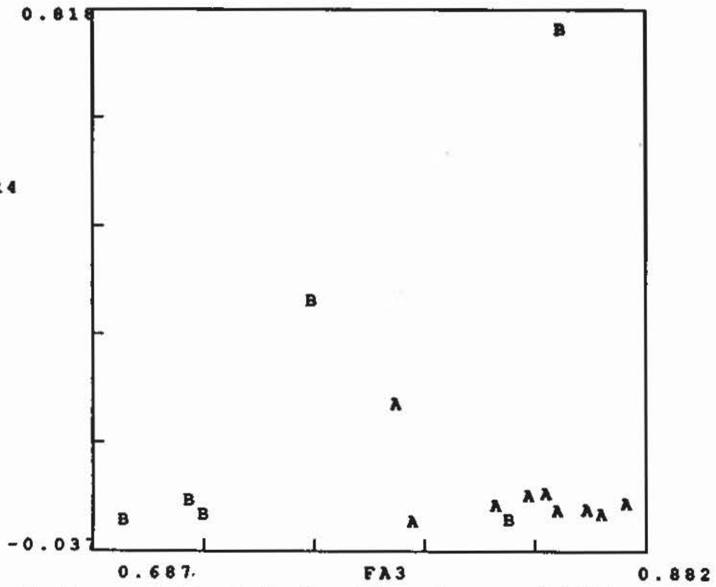


Fig. 5 – Same as in Fig. 4b for d = 1 (from Bietti *et al.* 1994).

Apart of the enlargement of the sample, this new set of data will be a test for all a series of basic problems:

a) choosing the best magnification in the pictures: our impression is that 200X may be too low but 400X too high, thus enhancing problems of focus in the image, we think that 300X is probably a good compromise;

b) the working time on the various materials should be varied: it may well be that two hours of work on a soft material, such as meat, for instance, produces a polish similar to the one obtained, say, by half an hour work on bone or antler;

c) one should also try the "superimposition" of activities on different materials, analyzing, for instance, the polish produced by work on meat followed by a work on hide;

d) the set of experiments presented here has been performed on the same quality of flint (the well known flint of the Gargano, in Apulia): one should try to study the polishes on different types of flint.

All these analyses have to be done only on experimental tools: only later we can try to transfer the informations obtained on the archaeological materials: there is a large body of statistical techniques well suited to this end (see, for instance, Bietti 1993).

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ABSTRACT

In this paper we describe an attempt of application of image processing for the texture study of the use wear polishes on flint artifacts, experimentally obtained on two types of materials: wood and hide.

The quantification of the textural properties of the images, obtained with a high magnification (200X) metallographic microscope follows strictly the rules indicated by HARALICK *et al.* in 1973. 22 textural features have been obtained from the image and a statistical analysis then allows to discriminate between the two classes of materials. The techniques employed, T-test and linear stepwise discriminant analysis, show that the discrimination between tools working wood and working hide is quite good, in the case of distance between the pixels = 1.

Possibilities of future and more refined analyses are then discussed at the end of the paper.