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# COMPOSITION OF THE LA GRAUFESENQUE, BANASSAC AND MONTANS TERRA SIGILLATA

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## 1. INTRODUCTION

For a few years the laboratory has been undertaking a systematic study on the Terra Sigillata compositions. At present the products from more than sixty workshops have been studied in a more or less thorough way, and several thousands of measurements have already been carried out on this type of ceramics. We had many objectives in this work. The first question was to resolve some methodological problems that come up when one tries to determine with physical and chemical processes the origin of the ceramics that have been found in excavations, or to put it in a simpler way, to establish subdivisions in any set of potteries. Now, Terra Sigillata has the advantage of being common to many workshops that have been excavated, which ensures that one starts from a sure archaeological basis; so it is possible to test the value of the criteria used to recognize the origins or to establish subdivisions. Another aim is a practical application of the previous one. It consists in giving the archaeologists a method which allows them to get a better understanding of the problems raised by this type of ceramics, and to make sure of the provenance of many specimens for which the workshop cannot be found using only stylistic criteria. Lastly, the technological problems specific to the manufacture of Terra Sigillata are also studied.

In a preliminary paper published in this review (Picon *et al.* 1971) we presented the diagrams of the Lezoux, Lyon and Arezzo Terra Sigillata. Since that time, these diagrams have been completed and improved, while new ones related to many other workshops were added. We have not published all of them, but only those of special interest, either because they have been asked for by many archaeologists, or because they show new characteristics, as for example, the diagrams of the La Graufesenque, Banassac and Montans workshops.

## 2. FORMING OF THE DIAGRAMS

To form the diagrams of each workshop, potsherds were chosen which offered the widest possible range, both of date and of geographical location within the production centre. For La Graufesenque, potsherds coming from excavations on the left and right bank of the Tarn were selected as well as pieces found down at the main workshop (Raujolles) (Hermet 1934, Labrousse 1966 and 1972). For Montans, some pieces from the right bank of the Tarn (Saint-Sauveur) and from the site of Crambade were added (Durand-Lefebvre 1946

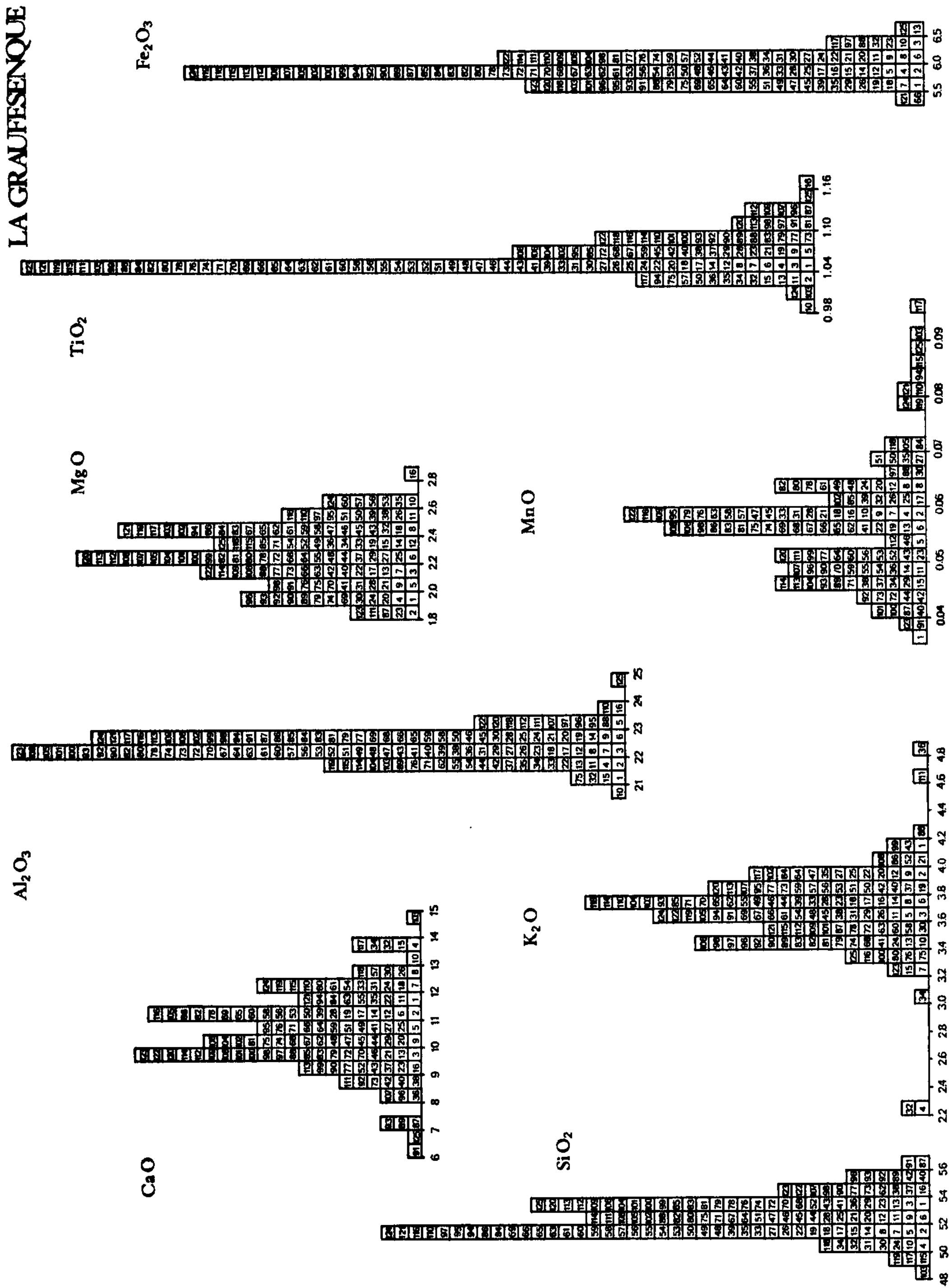


Figure 1 *Compositions diagrams of La Graufesenque workshop.*

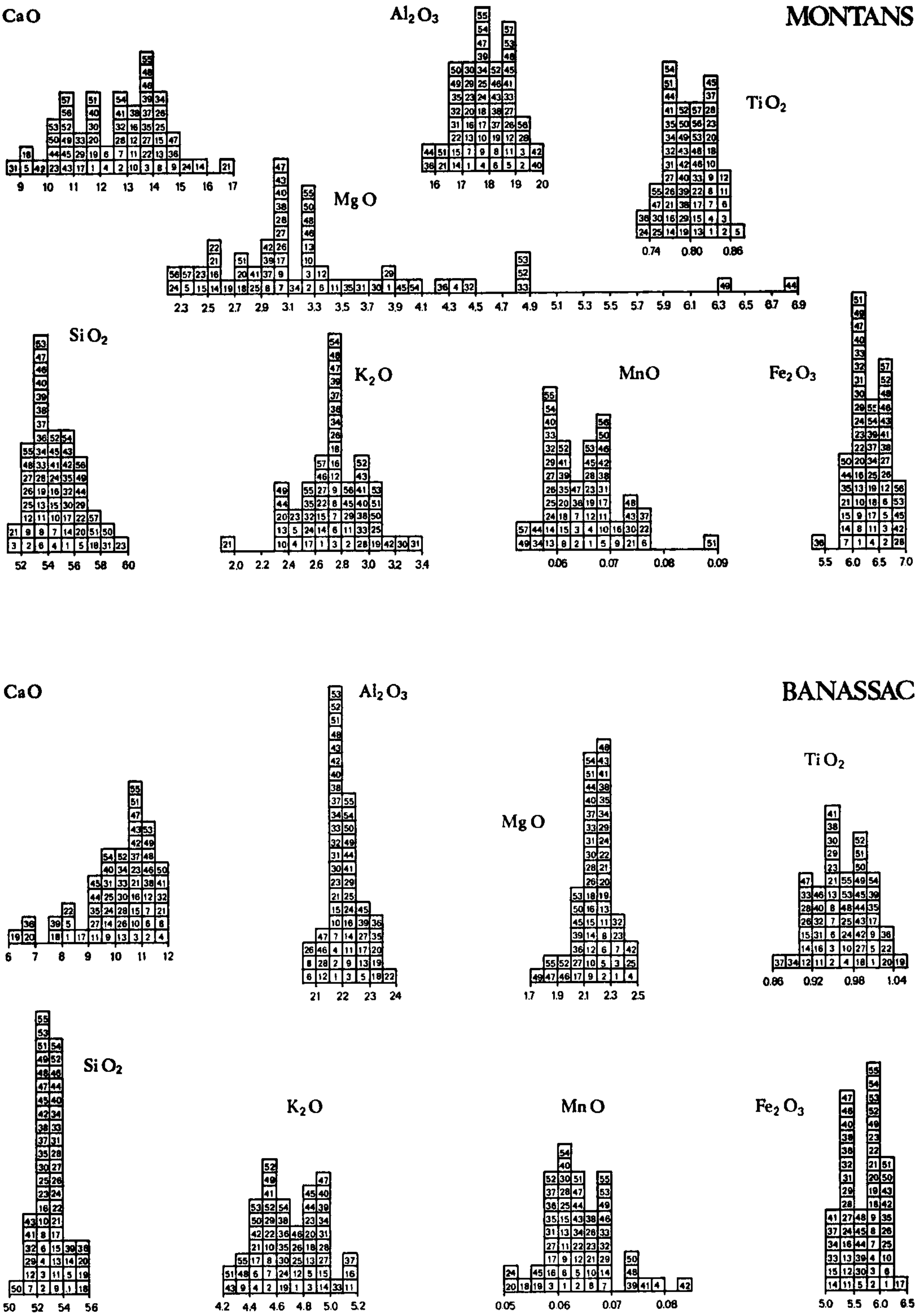


Figure 2 *Compositions diagrams of Montans and Banassac workshops.*

Labrousse 1968, Martin 1974). And lastly for Banassac, ceramics picked up from different excavations were gathered, with a few coming from collections on the surface at places which have not yet been excavated (Hofmann 1966, Picon and Hofmann 1974).

The method of analysis has already been described in the preliminary paper (Picon *et al.* 1971). The only modification that has been introduced is some adjustment of the potassium and titanium measurements. They are given in an appendix. The diagrams related to the three production centres are in figures 1 and 2. For La Graufesenque, 125 specimens appear on them, for Banassac 55 and for Montans 57. A full description of the specimens is not given due to their large number, and their wide variety.

## 3. DISTINCTIVE FEATURES OF THE LA GRAUFESENQUE, BANASSAC AND MONTANS PRODUCTS

The average value $\bar{m}$ of the chemical components of ceramics for each one of the three centres, as well as the corresponding values of the absolute standard deviations $\sigma$ and relative standard deviations $\sigma\%$, have been listed in table 1.

Table 1*

| *Components* | *La Graufesenque* | | | *Banassac* | | | *Montans* | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\bar{m}$ | $\sigma$ | $\sigma\%$ | $\bar{m}$ | $\sigma$ | $\sigma\%$ | $\bar{m}$ | $\sigma$ | $\sigma\%$ |
| CaO | 10.7 | 1.49 | 13.9 | 10.2 | 1.35 | 13.2 | 12.6 | 1.78 | 14.1 |
| $Fe_2O_3$ | 5.95 | 0.23 | 3.9 | 5.70 | 0.35 | 6.1 | 6.35 | 0.31 | 4.9 |
| $TiO_2$ | 1.07 | 0.030 | 2.8 | 0.97 | 0.038 | 3.9 | 0.80 | 0.035 | 4.4 |
| $K_2O$ | 3.70 | 0.31 | 8.4 | 4.70 | 0.23 | 4.9 | 2.75 | 0.25 | 9.0 |
| $SiO_2$ | 52.7 | 1.53 | 2.9 | 53.1 | 1.09 | 2.1 | 54.7 | 1.79 | 3.3 |
| $Al_2O_3$ | 22.5 | 0.56 | 2.5 | 22.1 | 0.63 | 2.8 | 17.9 | 0.95 | 5.3 |
| MgO | 2.30 | 0.21 | 9.1 | 2.20 | 0.14 | 6.4 | 3.35 | 0.89 | 26.5 |
| MnO | 0.058 | 0.0109 | 19.0 | 0.064 | 0.0062 | 9.6 | 0.066 | 0.0066 | 10.1 |

* The values are expressed in percents.

The examination of the values in table 1 and in figures 1 and 2 shows immediately that there is an obvious similarity between the compositions of La Graufesenque and of Banassac while the ones of Montans are quite different from the other two. This fact should not be a surprise, as it simply relates to the geological situation of the three centres. La Graufesenque and Banassac are both situated in the Causses and more precisely on the liasic clays, whereas Montans is situated outside the Causses on the tertiary sediments of the 'molasses de l'Agenais' (see figure 3).

It follows that there is no difficulty in distinguishing the Montans products from the ones of the two other centres. The $Al_2O_3$ percentage is always under 19.6 for Montans, while for La Graufesenque it is over 21.0 and for Banassac over 20.8. In the same way the $TiO_2$ percentage is under 0.88 for Montans but over 1.00 for La Graufesenque and over 0.88 for Banassac. Important differences can also be observed between Montans and the two other centres in the distribution of potassium, magnesium and iron.

On the contrary, comparison between the diagrams of La Graufesenque and of Banassac

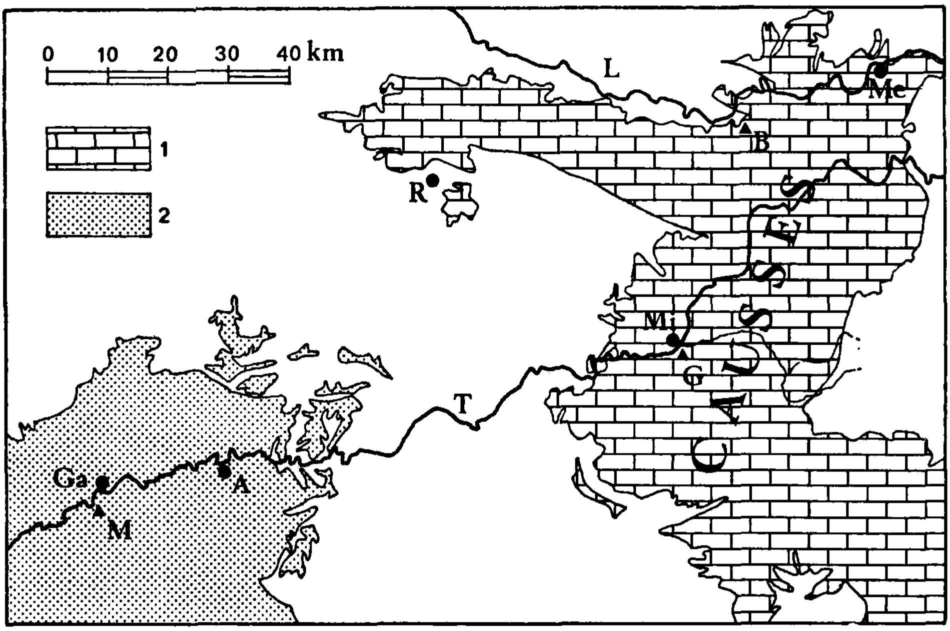


Figure 3 *Map showing the geographical and geological situation of La Graufesenque (G), Banassac (B) and Montans (M) workshops. The jurassic sediments of the Causses corresponds to* (1) *and the tertiary sediments of the Bassin Aquitain corresponds to* (2). *The main towns are Albi (A), Gaillac (Ga), Mende (Me), Millau (Mi), Rodez (R), and the main rivers are the Tarn (T) and the Lot (L). The north is in the upper part of the map.*

show that it is very difficult to differentiate the products from these two centres. The main difference is in connection with $K_2O$, but the two distributions are very close to each other. This necessitates the use of more elaborate methods to improve the separation between these two workshops.

## 4. A STATISTICAL APPROACH

The method used to separate the products from the workshops of La Graufesenque, Banassac and Montans is derived from discriminant functions in multivariate analysis (de Bruin *et al.* 1972, Laffitte 1972, Romeder 1973, Ward 1974). It is a general method which can be applied to any number of groups (here we are talking more generally about groups than workshops, for it is very often that one is led to distinguish several composition groups inside the same workshop). The composition of a given potsherd $x$ is successively compared to the compositions of a certain number $k$ of groups, and then, the probabilities that this potsherd has to belong to each one of these different groups are calculated. In other words, it is a matter of classifying a given analysis into a composition group which has been previously defined.

Let $P_i$ be the probability of the potsherd $x$ belonging to the group $i$ among all $k$ possible groups. One has (Laffitte 1972) $P_i = d_i(x)/\sum_{j=1}^{j=k} d_j(x)$

with $d_i(x) = (2\pi)^{-n/2}.|C_i|^{-1/2}.\exp\{-1/2(x-\bar{m}_i)'C_i^{-1}(x-\bar{m}_i)\}$

$$C_i = \begin{pmatrix} \sigma_1^2 & \sigma_1\sigma_2 r_{12} & \sigma_1\sigma_3 r_{13} \cdots\cdots\cdots\cdots \sigma_1\sigma_n r_{1n} \\ \sigma_2\sigma_1 r_{21} & \sigma_2^2 & \sigma_2\sigma_3 r_{23} \cdots\cdots\cdots\cdots \sigma_2\sigma_n r_{2n} \\ \cdots\cdots & \cdots\cdots & \cdots\cdots\cdots\cdots\cdots\cdots \\ \sigma_n\sigma_1 r_{n1} & \sigma_p\sigma_2 r_{n2} & \sigma_p\sigma_3 r_{n3} \cdots\cdots\cdots\cdots \sigma_n^2 \end{pmatrix}$$

$d_i(x)$ is the density function related to $x$, for the group $i$.

$C_i$ is the determinant of the matrix $C_i$ (covariance matrix).

$(x-\bar{m}_i) = (x_1-\bar{m}_1, x_2-\bar{m}_2, x_3-\bar{m}_3, \ldots\ldots\ldots\ldots, x_n-\bar{m}_n)$

$(x-\bar{m}_i)'$ is the transpose of $(x-\bar{m}_i)$

$x_1, x_2, x_3, \ldots\ldots x_n$ are the percentages of the components 1, 2, 3, ......, n, in the sherd $x$ which is to be compared with the group $i$ (or workshop $i$).

$\bar{m}_{,1}\ \bar{m}_2, \bar{m}_3, \ldots\ldots, \bar{m}_n$ are the average values of the components of the group $i$.

$\sigma_1, \sigma_2, v_3, \ldots\ldots, \sigma_n$ are the standard deviations related to the components 1, 2, 3, ....... ,n, and $r_{12}, r_{13}, r_{23}, \ldots\ldots$ the correlation factors of the components taken two by two.

In practice the potsherd $x$ is assigned to the group $j$ for which the density function $d_j(x)$ is higher than all the others, that is to say, to the group $j$ for which the probability $P_j$ is close to 1. When the highest probability is inferior to 0.9, which is very rare indeed, the assignment is left unresolved between the two groups or workshops the probabilities of which are the highest. Therefore, it is necessary to make sure that the density function $d_j(x)$ is included between the extreme values of the density functions $d_j$ relating to the potsherds making up the reference group $j$.

One might think that it was possible to make the calculations easier by using a method of linear discrimination rather than a quadratic one. By doing so, a same average covariance matrix $C$ would be used for all the workshops. We have chosen the quadratic discrimination for two reasons:

1. The covariance matrices are in fact quite different from one workshop to another. That is how ratios higher than $10^6$ are very often found between the determinants $|C_i|$.
2. In practise the quadratic discrimination does not imply that each one of the distributions is a Gaussian one (Romeder 1973). However, such has been the case in almost every workshop that we have studied. On this matter let us observe that among all the workshops studied we have never found any distribution which could have induced us to use a logarithmic pattern rather than a linear one as it has been suggested in some cases (Al Kital *et al.* 1969, Harbottle 1970).

## 5. APPLICATION AND RESULTS

To judge the potential of such a calculation with a view to improving the separation between workshops, we tested it for each one of the 237 potsherds which form the three reference groups of the La Graufesenque, Banassac and Montans workshops. In the previous formulas we took $k = 3$ (number of workshops) and $n = 8$ (number of components).

Among the factors which are determined before reaching the probabilities $P_i$, the correlation factors, although very important to the final results, have in most cases little geochemical signification. As a rule, they give false opposite correlations due to the fact that the total number of components remains equal to 100, so if one of the components increases, the calcium for example, it is inevitable that the others decrease. The only indisputable correlation which shows in the examples studied here is a Fe–Al correlation, with $r = 0.86$ for Montans, which can be compared to the values $r = 0.04$ and $r = 0.10$ for La Graufesenque and Banassac.

The results of the calculation of probabilities $P_i$ are as follows:

1. For the 55 sherds of Banassac, probabilities were found in favour of this workshop which varied between 1 and 0.985. Hence, it can be seen that the potsherds of Banassac finally do not look like the ones from La Graufesenque, in contrast to what was found with only a superficial examination of figures 1 and 2. It should be noticed that the potsherds ref. 43 and 51, which are the nearest to La Graufesenque on the diagram of $K_2O$ (figure 2), give only 0.0146 and 0.0001 as respective probabilities in favour of this workshop. Likewise, the sherds ref. 19 and 20 which are the nearest to La Graufesenque for $TiO_2$ (figure 2) give, in favour of the same, 0.00001 and 0.00001 as probabilities. Now we should keep in mind that the La Graufesenque and Banassac diagrams show differences as far as $K_2O$ and $TiO_2$ are concerned (figures 1 and 2).
2. As to the potsherds from La Graufesenque, the probabilities in favour of this workshop vary between 1 and 0.997, except for the sherds ref. 36 and 111 whose positions on the $K_2O$ diagram are parallel to the Banassac products. However, these two sherds still differ from the Banassac ones since we have the following probabilities:

| *Sherd ref.* | *La Graufesenque* | *Banassac* | *Montans* |
|---|---|---|---|
| 36 | 0.378 | 0.622 | 0.000 |
| 111 | 0.309 | 0.691 | 0.000 |

Now we have seen that the potsherds from Banassac always present a probability over 0.985. These two potsherds, ref. 36 and 111, are a typical example of the problems which arise during the making up of the reference groups. The results of the previous calculations show that these two sherds are different from both those of La Graufesenque and Banassac. This is clearly confirmed in the examination of the density functions. The density functions for these two sherds are much lower than all those potsherds found in the Banassac workshop. Therefore, taking into account the abnormal values of the density functions and those of the probabilities themselves, there should be no reason to assign such compositions to Banassac.

In fact these two potsherds can hardly be considered as belonging to the main La Graufesenque group the composition of which yield an almost Gaussian distribution (with the exception of the compositions ref. 4 and 32 which we will discuss later on). It is rather a different kind of clay whose distribution is probably Gaussian, but unfortunately we only have two specimens.

The method of calculation used is probably one of the best and satisfies any distribution, resulting for example, as in La Graufesenque, in the superposition of at least two Gaussian distribution curves. In practice it is better to consider these distributions separately. Therefore this will be the solution we will adopt for the small group made up of the two potsherds ref. 36 and 111 as soon as more specimens belonging to this small group are found. In the meantime the solution for only one group is utilized. This solution avoids the risk of confusing the products of La Graufesenque with those of Banassac. This is because of the conditions imposed upon the density functions to remain between the extreme values of the density functions relating to the potsherds making up the reference groups of each one of the two workshops.

The sherds ref. 4 and 32 could not cause any difficulty because of the way in which the problem has been fixed. These sherds are in fact more distant from the Banassac ones than any other piece of La Graufesenque, and they always remain very distant from Montans. Therefore it is normal to find for them probabilities equal to 1 in favour of La Graufesenque. However, here again we are dealing with two sherds not belonging to the main distribution, such as already was the case for the potsherds ref. 36 and 111. They must also be considered as being the first step of a third distribution, probably Gaussian. What has been said about the small group made up of potsherds ref. 36 and 111 can also be applied here.

3. For the 57 sherds of Montans probabilities all equal to 1 have been found in favour of this workshop. The probabilities in favour of La Graufesenque or Banassac are as an average, from $10^{30}$ to $10^{40}$ times lower. That fits with the difference that exists between the compositions of these two workshops and the one of Montans.

## 6. EXTENSION

The previous calculation method is meant to classify any potsherd whatever within the set of the composition groups that we have defined during our study of Terra Sigillata There are about 80 of these groups at the moment as one has had very often to define several groups for one workshop. Therefore it is a method which requires a computer, and which supposes that all the groups that any potsherd may belong to are known. It brings up no peculiar problem if it is possible to admit that all woikshops are known, but it is always necessary to verify it, even for Terra Sigillata. In fact, though Terra Sigillata is considered to be well known, we have discovered some unknown workshops when doing this checking (Picon *et al.* 1973*b*).

The possibility for detecting new workshops (or new groups) comes from the fact that an analysis can very well not be classified in any of the groups already listed, which is the result of the conditions imposed upon the density functions. However, it is possible to wonder whether the reduced number of components taken into consideration does not increase in a very excessive way the risks of confusing, for example, the products from a well-known group with the products of another group not yet known, both products having similar characteristics. It is not yet possible to give a satisfactory answer to this question, more especially as the risks of confusion depend first of all upon the geological data. It is obvious that risks can be very high, especially in workshops having the same geological situations. To be more precise, surrounding each workshop, one should determine a 'zone d'incertitude' (Picon 1973*a* and *c*), an area in which the method of analysis used does not permit any differences between the clays. Therefore, strictly speaking, a potsherd, because of its composition, should not be assigned to a defined workshop, but only assigned to the area previously mentioned.

In spite of what has just been said, an average risk of confusion can be evaluated from the results obtained with all the Terra Sigillata workshops. Now, if we consider all the possible combinations of the workshops taken two by two, it will be possible from now on, even if the study is not yet completed, to take note that more than 99% of these combinations are completely resolved. Even when a combination has not been resolved, only a very small number of potsherds can be wrongly assigned. These results will have to be defined more precisely and compared with those obtained with other methods. However, those results are enough to justify the use of the method previously stated for the solution of many archaeological problems (Picon 1974*b*).

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## APPENDIX

Some results that have been previously published (Picon *et al.* 1971) have been altered as a result of recent adjustments of potassium and titanium measurements. We shall give the lower and the upper extreme values of the groups after the correction for the two involved components.

| | | | |
|---|---|---|---|
| $K_2O$: | Lezoux, | ref. 58 = 2.80% | ref. 109 = 4.15% |
| | Lyon, | ref. 42 = 1.75% | ref. 7 = 2.50% |
| | Arezzo, | ref. 23 = 2.10% | ref. 69 = 2.85% |
| $TiO_2$: | Lezoux, | ref. 110 = 0.69% | ref. 48 = 0.89% |
| | Lyon, | ref. 48 = 0.48% | ref. 38 = 0.69% |
| | Arezzo, | ref. 50 = 0.83% | ref. 14 = 0.96% |

For $TiO_2$ the aberrant values (Lyon ref. 3 and Lezoux ref. 90) come probably from local heterogeneities; they have been integrated into the group after new analyses.