

## A LYONS BRANCH OF THE POTTERY-MAKING FIRM OF ATEIUS OF AREZZO

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### 1. INTRODUCTION

#### 1.1. *Romans and the Gallic market of ceramics*

During the second and the first centuries B.C. large quantities of Italic ceramics, mostly Campanian A and B with black glaze (Lamboglia 1952) appeared on the Gallic market. Shortly thereafter imitations of these wares were produced in Gallic workshops, particularly those in the region of Vienne and Lyons in the Rhone Valley.

After the middle of the first century B.C., a new class of ceramics with a red glaze§ ('terra sigillata'), mostly signed, appeared in Italy. This pottery came predominantly from the workshops which were producing Campanian B (Goudineau 1968) especially those in Arezzo. These new ceramics were soon exported and met with considerable success. Again, this work was quickly imitated in Gaul, and some of the imitations came from the workshops of Loyasse in Lyons. These imitations, however, were technically very different from their models. In particular, the local potters could not obtain a red glaze comparable to that from the workshops of Arezzo, but only a porous one of low quality. These imitators also distinguished themselves by not signing most of their productions.

The success of their red glazed products probably stimulated the potters of Arezzo to establish branches closer to the new markets which had been opened by the Roman conquests in Gaul and on the Rhine. This interpretation is supported by the existence of the complex of workshops of La Montée de la Murette in Lyons, which did not produce imitations but, and apparently for the first time in Gaul, red pottery which had all the characteristics of those from Arezzo. Furthermore, out of the fourteen fragments of moulds which have been discovered in La Murette, two show a distribution of major chemical elements which suggests a provenience from Arezzo (Picon *et al.* 1973). In addition, the major-element distribution of thirteen stamps found in La Murette also indicates the same provenience. Finally, the names (Lasfargues *et al.*) of many of the masters and slaves from the pottery workshops of Arezzo are found among the signatures of pots unearthed in La Murette.

Among the large firms of Arezzo, Ateius held the attention of scholars largely because of its prominence in the market in Gaul and in the Germanic frontier garrisons (Fiches 1972, Lombard 1971, Ettliger 1962). Because many sherds with the Ateius signature had

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§ The word 'glaze' is not strictly correct for this type of ceramic, however, we use it here for lack of a better word.

been found in Gaul and none in Arezzo, it had been suggested by Ritterling and Oxé that these potteries may have been locally made. These arguments were revised after the discovery of the Ateius workshop in Arezzo (Maetzke 1959). The possibility still remains, however, that some Ateius pottery was made in Gaul although none has been found in excavations of pottery workshops up to the present time.

Recently a systematic study (Picon *et al.* 1971) was made by X-ray fluorescence analysis of the abundances of the major chemical elements of many Italic ceramic imports found in Gaul. Six sherds bearing the Ateius signature had chemical composition patterns or 'fingerprints' which were not only distinctly different from that of pottery excavated in Arezzo, but were rather similar to those of pottery excavated in workshops around Lyons.

Although this information pointed to Lyons rather than Arezzo as the place of manufacture of these vessels, it was thought that a more detailed examination of chemical compositions might provide a surer basis for making a judgement.

## 2. EXPERIMENTAL TECHNIQUES

### 2.1. Trace elements and provenience problems

Besides the major elements found in pottery there are many more which occur only in minute traces, often in just a few parts-per-million (ppm). The potential importance of these trace elements for determining provenience of pottery by chemical fingerprinting lies in the breadth of chemical properties which are included in such a large array of elements. Clays arise from the weathering of certain rocks which might be quite similar in composition. Chemical fractionations take place in forming the clays, and environmental conditions will no doubt effect various elements differently. If one examines elements which exhibit a diversity of chemical properties, there will be more chance for detecting the consequences of subtle environmental differences between one place and another.

There are some obvious requirements for success in using trace elements for this purpose and two of these are interlinked. For a trace element to be useful, it must not behave chaotically, that is, its distribution within a clay source must be quite uniform. If pottery from one source showed a wide dispersion in values for this element, it would have little use in distinguishing one source from another. In this regard, experience has shown that many of the trace elements are just as well behaved as the major constituents.

Closely connected with the requirement that diagnostic elements have a small variability within a source is the necessity for measuring them with the required accuracy. Neutron activation analysis (NAA) is a technique which combines accuracy and sensitivity for a wide array of elements. A considerable number of elements present in clays can be measured to an accuracy of a few percent or better, even though they are present in the parts-per-million range.

It is the practice in such fingerprinting to draw inferences from pottery samples themselves rather than to compare them with clays from the suspected region of manufacture. In principle, it might be more convincing to demonstrate that a piece of pottery relates directly to a specific clay source but there are problems in attempting to do such 'absolute provenience' work. Firstly, it is by no means easy to decide where the ancient potters drew their clays nor even whether the deposits still exist. In addition, practices employed in pottery-making can cause changes in chemical composition which would negate the opportunity to relate pottery directly to the clay. Such changes could occur in the processes of levigating

clay, which removes coarse particles including some limestone; tempering clay, which introduces organic materials, rock products or old pottery into the clay; and firing calcareous clays at different temperatures, which can result in large variations in the carbonate content.

By analyzing pottery alone, one relies upon some conservatism by the potters in the selection of their clays and in their refining and tempering practices. (Some deductions of the uniformity of these practices will appear in the discussions which follow.) With this supposition, ceramics made by particular potters from a given clay source will be uniform.

A group of pottery can be considered to be a suitable reference group for locally-made ware if it meets a couple of criteria: (1) It belongs to the region of excavation according to archaeological evidence. This is particularly convincing if waster sherds are found in or about kiln areas. (2) The composition of the pottery is uniform. Often, a number of different styles of pottery, which belong to different time periods, all show the same composition, and such findings enhance confidence in the deduction that each group was locally made.

## 2.2. *Statistical criteria for NAA*

As mentioned, NAA is a technique which can measure a wide array of elements with good accuracy and therefore it well adapted to provenience determination for pottery. In the modification used for the present work (Perlman and Asaro 1969 and 1971), some fifty elements are looked for in each pottery sample; about forty are usually observed, and the abundances of over twenty of these elements (the ones used to fingerprint the pottery) are measured with an average precision of  $\sim 2\%$ .

Some simple statistical criteria (Asaro and Perlman 1969, M. Artzy *et al.* 1973) have been employed to arrange and interpret the chemical abundance of data in order to judge matters of provenience. The treatment is deliberately kept simple in order not to lose sight of the fact that we cannot easily prove that some of the statistical parameters have the necessary randomness for a rigorous analysis. As an example, the abundances of the various elements selected for the characterization of pottery vary independently to some extent, but also exhibit some coherent behavior for many of the elements. It will be seen, however, that the assignment of provenience does not hinge upon fine distinctions.

The first step in the statistical analysis is to obtain the chemical profile for a reference group. The reference group is generally a collection of sherds for which we assume, provisionally, that the provenience is known. For each element, the average value of its abundance ( $M$ ) within the collection is obtained and the spread of values is computed in the form of the root-mean-square deviation ( $\sigma$ ). A tabulation of  $M \pm \sigma$  for all the diagnostic elements makes up the chemical profile or 'fingerprinting' for this pottery group. For pots of unknown provenience to be members of this 'reference' group, the abundances of the various elements should agree with the mean values of the group within certain limits. If we make these limits very small (e.g. one  $\sigma$  for  $\sim 20$  elements) we will be able to ascertain the provenience of only a small portion of the pots ( $\ll 1\%$ ) which actually belong to a reference group. If we make the limits much larger, on the other hand (e.g. 4  $\sigma$  for  $\sim 20$  elements), we would be able to classify essentially all of the pots which are members of the group but would enhance the probability of overlapping chemical compositions which would necessitate a more complex statistical treatment. The limits best suited to a particular problem depend on the degree of homogeneity of the reference group and the similarity in composition of other such groups. The following example would serve to classify about 99% of the pots

of unknown provenience which are members of known groups and adequately distinguishes between the reference groups. From an analysis for 20 elements, all pots of unknown provenience would be considered a member of a given group *except* those for which: (1) one or more elements differed from the group means by  $\geq 4\sigma$ ; (2) or two or more elements differed by  $\geq 3\sigma$ ; (3) or five or more elements differed by  $\geq 2\sigma$ ; (4) or thirteen or more elements differed by  $\geq 1\sigma$ .

Sometimes all or nearly all of the measured abundances of a sherd will deviate systematically from the group averages by almost a constant factor. As will be discussed in a later section, however this can be interpreted as a dilution of the clay of the sherd or of the group by undetected major constituents, e.g. water and  $\text{CO}_2$ , and appropriate corrections to the abundances can be made.



Figure 1 Map of Europe showing the location of sites in this study

For a given pottery group the smaller the values of  $\sigma$  for the various elements and the larger the number of useful elements included in the analysis, the smaller is the probability of making an erroneous assignment of provenience by this method. In practice, it has been found that if about twenty carefully selected elements are used and the average value for  $\sigma$  of their abundance is 10% or less in the reference group, then the determination of provenience is reliable. The selected elements should be measured with a precision substantially better than 10% and then should vary somewhat randomly with respect to each in the different clay beds, but should not vary erratically in the same pot.

To compensate for this possible erratic behavior, as well as the uncertainties in the assumption of a Gaussian distribution of chemical abundances and the occurrence occasionally

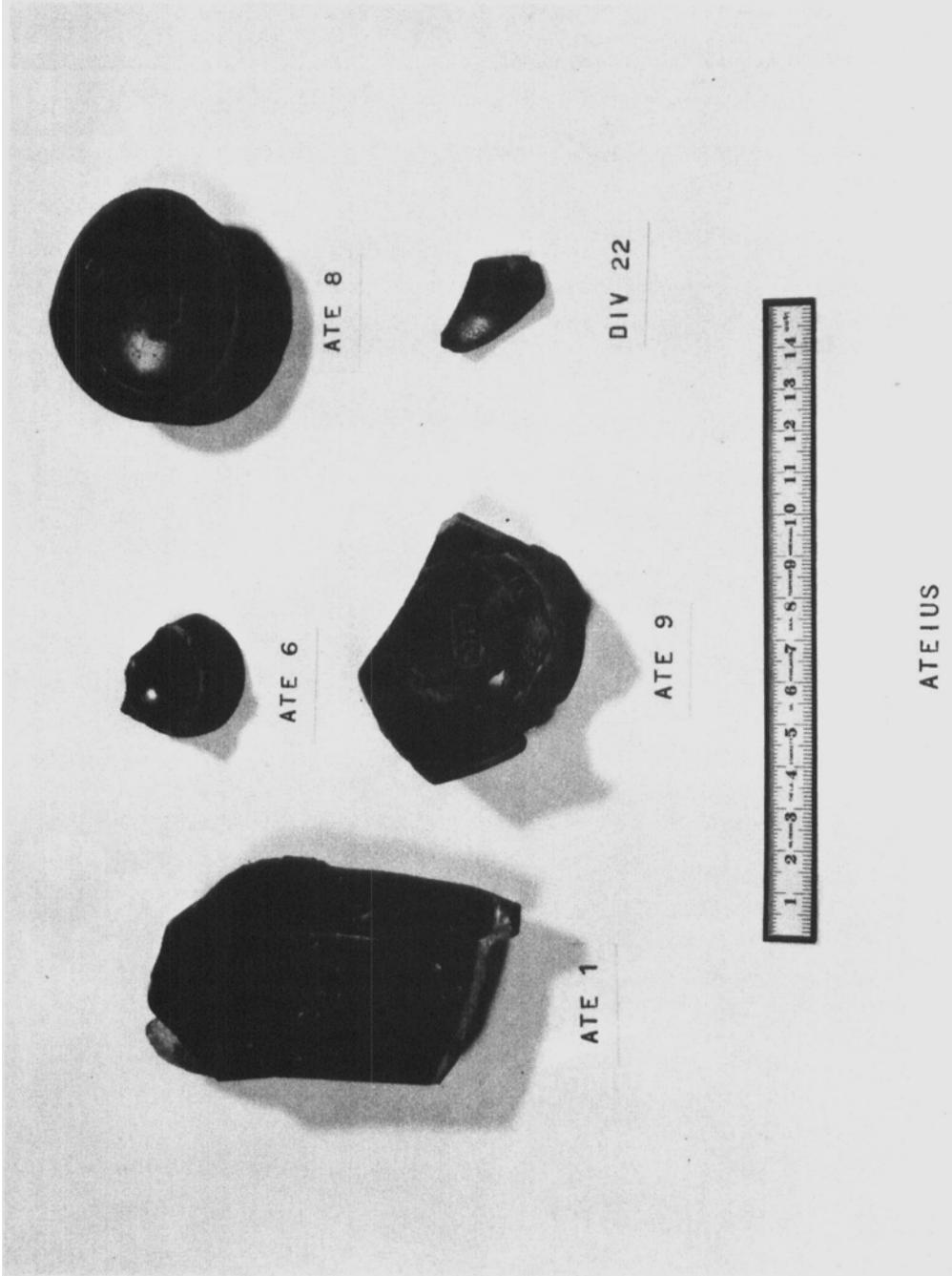


Plate 1 Five terra sigillata sherds bearing the stamp of Ateius.

of low probability statistical events, the one element out of the twenty which shows the poorest agreement between the pot of unknown provenience and the reference group has often been discarded. In the present experiments we were fortunate and this was not necessary. It is possible and even likely that the foregoing criteria might not be sufficient to distinguish potteries made from clay beds which have a very similar geochemical and environmental history, such as deposits laid down along the course of a long river, and for those more stringent criteria would be necessary.

Table 1 Previous XRF measurements.\* Comparison of chemical abundances of sherds selected for NAA measurements with those of the total group

Site: Number of sherds	Arezzo		Loyasse		La Mulette		20	
	$T^\dagger$	$S^\ddagger$						
	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$
Si $T$ (%)	25.4	0.7	26.96	0.89	28.13	0.87	24.85	1.34
Si $S$	25.1	0.5	26.5	1.2	28.1	0.9	25.0	2.0
Al $T$	9.6	0.3	6.37	0.21	7.93	0.40	6.79	0.28
Al $S$	9.5	0.3	6.45	0.37	8.0	0.4	6.8	0.4
Mg $T$	2.35	0.10	0.89	0.16	0.86	0.18	1.23	0.17
Mg $S$	2.36	0.11	0.87	0.16	0.88	0.23	1.25	0.12
Ca $T$	8.6	1.3	13.50	1.32	9.94	1.24	15.80	2.04
Ca $S$	9.4	1.1	13.39	2.13	10.0	1.5	16.0	3.2
K $T$	2.07	0.14	1.76	0.08	1.82	0.12	1.72	0.21
K $S$	1.99	0.11	1.77	0.04	1.80	0.09	1.63	0.25
Ti $T$	1.56	0.02	0.33	0.03	0.38	0.02	0.31	0.01
Ti $S$	0.53	0.02	0.34	0.04	0.38	0.02	0.30	0.01
Fe $T$	5.10	0.19	3.20	0.16	3.84	0.25	3.67	0.15
Fe $S$	5.16	0.17	3.22	0.13	3.80	0.25	3.57	0.13

\* Picon *et al.*, 1971.

†  $T$ : total sherds in group.

‡  $S$ : those sherds selected for NAA.

### 2.3. Selection of sherds

The sherds selected for NAA were taken from larger groups which had been previously analyzed (Picon *et al.* 1971) by X-ray fluorescence (XRF). That the ones selected for NAA are representative of the larger collection can be seen from the XRF data in table 1. A map of the sites studied in this work is shown in figure 1.

*Pottery from Arezzo* Twenty-three sigillata sherds excavated at Arezzo were selected for analyses. These sherds are *a priori* likely to be of local manufacture since they seem to be 'factory rejects'.

*Pottery from Lyons* As reference sherds from Lyons, we used pieces of broken, misbaked, or deformed pots of terra sigillata from dumps found near the kilns. Twenty-two samples excavated from La Mulette and 6 from Loyasse were used in the present measurements. The coarse pottery found here was not appropriate as reference material because it was

definitely made from a different type of clay, which among other features, was not calcareous. It has been noted before in studies of pottery from Cyprus (Asaro *et al.* 1972) and from Lezoux, France (Vertet *et al.* 1970) that different types of clay were sometimes used to produce different styles of pottery.

*Ateius signed pottery* Four sherds with the Ateius signature (ATE-1-4) were analyzed which had been excavated in Strasbourg and one (DIV-22) which had been excavated in Lyons. None of these sherds, however, came from pottery workshops. Photographs of these five sherds are shown in plate 1.

#### 2.4. Sample preparations and measurements

*Carbonate measurements* The samples used for XRF measurements (Picon *et al.* 1971) had been refired in the laboratory at 1000°C prior to weighing, while those used for NAA were not. The substances removed in the refiring were most likely CO<sub>2</sub> and water. The CO<sub>2</sub> originated either from CaCO<sub>3</sub> (limestone) which was present in the clay before the original firing or which was reformed by absorption of CO<sub>2</sub> afterwards. Pottery fired at a low temperature retains its CO<sub>2</sub>, that fired at 1000°C or above loses it, and that fired at intermediate temperatures may lose varying amounts. A comparison between measurements on a sherd by the two techniques shows the amount of volatile material, and, if the sherd is calcareous and the CO<sub>2</sub> content is very low, indicates if it was well-fired. As will be explained below, it is possible to compare the earlier results from XRF measurements with the present NAA results even though one set of samples had been refired and not the other.

In order to determine the CO<sub>2</sub> content of some of the samples used for NAA measurements, a number of wet chemical analyses were made. The pottery powder was treated with cold 2N HCl and gently heated. The CO<sub>2</sub> released was entrained in stream of dry nitrogen, scrubbed with sulphuric acid and then dried over anhydrous Mg(ClO<sub>4</sub>)<sub>2</sub>. The CO<sub>2</sub> was then absorbed on ascarite and weighed. The CO<sub>2</sub> measurements were made by Lilly Y. Goda of the Lawrence Berkeley Laboratory.

*NAA measurements* Pottery powder was obtained from a sherd by first cleaning a surface and then drilling or scraping with sapphire or diamond-tipped tools. Alternatively, a small cleaned corner was broken off and ground with a mortar and pestle. 100 mg of the pottery powder was mixed with 50 mg of cellulose binder and pressed into a pill 1 cm in diameter.

The elemental compositions of the pills are determined from the gamma-ray spectra of radioactivities produced by neutron irradiation. The detailed procedure has already been described (Perlman and Asaro 1969), but since the date of that publication some modifications have been introduced which improved significantly the accuracy with which several of the elements can be determined. The analyzing system has also been automated, lessening the amount of personal attention required in operating the equipment to its capacity.

### 3. RESULTS

#### 3.1. Provenience

The chemical abundances measured by XRF for the sherds used in this work are shown again in table 2. These are arranged, however, into chemical groupings determined by NAA. Some of the entries in table 2 pertain to groups of sherds (the number of pieces appear just below the group designations); others are for individual sherds.

It will be noted that the twenty-three sherds considered to be from Arezzo still fall into

Table 2 Chemical abundances\* in pottery† measured by XRF

Group or sherd:	<i>ARE</i>	<i>MML B</i>	<i>MML-14</i>	<i>MML-15</i>	<i>LOY</i>	<i>LOY-3</i>
Quantity of sherds:	23	4			5	
Si(%)	25.1±0.5	23.7±0.4	23.8	25.8	26.0±0.6	28.9±0.6
Al(%)	9.5±0.3	6.6±0.3	6.5	6.7	6.4±0.4	6.9±0.3
Mg(%)	2.36±0.11	1.36±0.12	1.21	1.42	0.89±0.08	0.75±0.06
Ca(%)	9.4±1.1	17.9±1.3	17.9	14.8	14.2±0.6	9.2±0.4
K(%)	1.99±0.11	1.51±0.22	1.56	1.76	1.77±0.04	1.80±0.08
Ti(%)	0.53±0.02	0.30±0.01	0.30	0.31	0.32±0.02	0.44±0.02
Fe(%)	5.16±0.17	3.57±0.13	3.43	3.64	3.22±0.15	3.22±0.13
Group or sherd:	<i>MML A</i>	<i>MML-16</i>	<i>MML-3</i>	<i>MML-2</i>	<i>ATE</i>	<i>DIV-22</i>
Quantity of sherds:	13				4	
Si(%)	28.0±0.9	29.4	29.4	25.8	28.8±0.6	28.7
Al(%)	7.9±0.4	8.7	7.7	6.9	7.6±0.3	7.5
Mg(%)	0.88±0.23	0.81	0.69	1.21	0.81±0.06	0.88
Ca(%)	10.0±1.5	7.2	9.3	14.4	9.5±0.5	9.7
K(%)	1.80±0.09	1.91	1.80	2.04	1.98±0.08	1.76
Ti(%)	0.38±0.02	0.41	0.38	0.31	0.38±0.01	0.37
Fe(%)	3.80±0.25	4.16	3.74	3.71	3.55±0.12	3.53

\* If there is more than one sherd in a group, the two entries for a particular element are the average abundance of that element and the root-mean-square deviation for the indicated sherds. If there is only one sherd listed, the two entries for a particular element are the actual abundance and the experimental accuracy ( $1\sigma$ ).

† Pottery chemical groups: ARE (Arezzo), MML A and MML B (Montée de La Muette in Lyons) Loy (Loyasse in Lyons), ATE (Ateius signed pottery from Strasbourg). DIV-22 is an individual Ateius signed sherd found in Lyon. MML- and LOY- are individual sherds from Montée de La Muette or Loyasse.

a single group. However, the twenty-two sherds from Montée de La Muette which had been divided into two groups (Picon *et al.* 1971) have now had five sherds removed and tabulated individually under such headings as MML-14. Similarly, the group from Loyasse has had one sherd removed.

For each of the pottery groups, the mean value for each element is listed along with the root-mean-square (rms) deviation for the group. The last column in table 2 gives the values for a single sherd along with the respective measuring errors as given by the authors (Picon *et al.* 1971). Data on other single sherds are presented without measuring errors.

The abundances measured by NAA for the elements most suitable for provenience determinations are shown in tables 3 and 4. Table 5 shows nine other elements or compounds which have (1) nearly identical behavior with other elements in tables 3 and 4 (Ce and Lu), (2) very poor precision (Ni and K), or (3) have previously exhibited erratic behavior in otherwise good chemical groups (Ba, Sb, Zn, and CO<sub>2</sub>).

The format of tables 3 and 4 follows that of table 2, with a few additional entries. In the heading for each pottery group, there is an entry 'average  $\sigma$ ' which refers to the average value of the rms deviation for the twenty elements expressed as percent of the element abundances. This number is an index of variability in composition averaged over twenty elements. The entries labeled *F* (enhancement factor) in tables 3–5 will be explained below. The last two columns in table 4 (also in table 5) show the values of one standard deviation

Table 3 NAA abundances\* of selected elements in pottery from Arezzo and some from Lyons

Group or sherd:	ARE	MML B	MML-14†	MML-15†	LOY	LOY-3
Quantity of sherds:	23	4			5	
Average $\sigma$ :	5.2%	5.9%	$F = 1.08$	$F = 1.16$	8.6%	
Al(%)	9.23 ± 0.55	6.41 ± 0.23	6.06	6.18	5.37 ± 0.38	6.76
Ca(%)	9.5 ± 1.3	18.2 ± 2.4	17.3	15.2	12.7 ± 1.2	9.14
Dy	5.39 ± 0.21	4.58 ± 0.31	4.65	4.43	4.04 ± 0.44	5.31
Mn	1117 ± 41	905 ± 53	862	828	774 ± 89	673
Na(%)	0.606 ± 0.027	0.454 ± 0.014	0.449	0.423	0.507 ± 0.037	0.687
U	2.70 ± 0.09	2.61 ± 0.22	2.60	2.43	2.33 ± 0.33	3.18
Sm	6.56 ± 0.20	5.04 ± 0.05	5.07	5.07	4.69 ± 0.28	6.10
La	39.4 ± 1.1	29.7 ± 0.5	29.1	29.6	27.4 ± 1.7	35.0
Ti(%)	0.477 ± 0.024	0.270 ± 0.020	0.236	0.282	0.287 ± 0.015	0.384
Ta	1.241 ± 0.039	0.772 ± 0.018	0.787	0.799	0.785 ± 0.048	1.133
Co	22.55 ± 0.86	12.87 ± 0.19	12.82	12.74	10.27 ± 0.82	11.84
Sc	19.06 ± 0.59	11.07 ± 0.33	10.95	11.33	9.80 ± 0.69	12.56
Fe(%)	5.24 ± 0.19	3.71 ± 0.06	3.66	3.73	2.96 ± 0.09	3.20
Yb	2.79 ± 0.08	2.25 ± 0.05	2.26	2.29	2.19 ± 0.11	2.87
Hf	3.95 ± 0.12	3.06 ± 0.13	3.30	3.17	4.12 ± 0.47	6.73
Cs	6.98 ± 1.10	3.68 ± 0.61	4.32	3.77	5.30 ± 0.95	8.00
Cr	182 ± 6	79 ± 7	85	70	73 ± 6	85
Th	13.44 ± 0.47	10.48 ± 0.13	10.44	10.45	9.70 ± 0.62	13.26
Eu	1.465 ± 0.054	1.122 ± 0.018	1.124	1.145	1.017 ± 0.059	1.250
Rb	132 ± 16	82 ± 21	81	82	92 ± 19	126†

\* The two entries for each element in a group are the average abundance and the root-mean-square deviation. The values are expressed in ppm or in percent if indicated after the element symbol. See table 2 for heading descriptions.

† True abundance values are equal to the listed value divided by the enhancement factor,  $F$ .

‡ The average Rb counting error for the Loyasse sample was 16 ppm.

for the precision and accuracy of the NAA measurements on sherds of Group MML A, and these are generally typical of all of the measurements. The *precision* indicates how well multiple analyses on identical samples should agree if all were done by the same techniques used in the present work. The *accuracy* contains, in addition, systematic errors such as uncertainties in the calibration of the standard. These errors should be used in comparing these results with measurements made using other techniques or with different standards.

Table 6 shows how closely individual sherds which are of uncertain provenience or which are somewhat aberrant in composition conform to the chemical group averages. Table 7 shows a concordance between the sherd numbers used in the NAA and XRF measurements and those previously published.

*Arezzo pottery* The twenty-three sherds form a very homogeneous chemical group with an average value of  $\sigma$  for twenty elements of only 5.2% (see table 3). As this is well below the 10% upper limit discussed previously, the group is very suitable as a reference for assignments of provenience.

The calcium in the clay from which these sherds were made must have been present largely as  $\text{CaCO}_3$  because the variability in the Ca abundance is considerably larger (in both measurements) than that of the common clay mineral elements. As measurements of

Table 4 NAA abundances\* of selected elements in pottery like group MML A from La Muette

Group or sherd: Quantity of sherds: Average $\sigma$	MML A 13 6.4%	MML-16† F = 0.85	MML-3† F = 1.08	MML-2† F = 1.13	ATE 4 3.8%	DIV-22† F = 1.09	Pre- cision‡ 1.9%	Accu- racy‡
Al %	7.38 ± 0.48	7.16	6.92	7.20	7.32 ± 0.15	7.15	0.13	0.16
Ca %	10.7 ± 1.6	6.9	12.9	13.0	9.6 ± 0.6	11.2	0.5	0.5
Dy	5.32 ± 0.28	5.60	5.19	5.31	5.37 ± 0.16	5.05	0.14	0.30
Mn	858 ± 82	885	817	840	890 ± 61	855	9	14
Na %	0.363 ± 0.014	0.365	0.376	0.364	0.391 ± 0.012	0.384	0.007	0.009
U	2.60 ± 0.13	2.40	2.83	3.08	2.64 ± 0.10	2.53	0.03	0.23
Sm	6.09 ± 0.28	6.21	6.02	6.11	6.18 ± 0.10	6.19	0.03	0.13
La	34.7 ± 1.7	35.6	33.7	34.6	35.8 ± 1.1	35.2	0.5	0.7
Ti %	0.328 ± 0.021	0.324	0.300	0.293	0.331 ± 0.014	0.329	0.014	0.020
Ta	0.984 ± 0.041	0.957	0.966	0.977	0.994 ± 0.017	1.000	0.007	0.031
Co	14.29 ± 0.78	14.47	14.78	11.74	14.09 ± 0.92	12.99	0.19	0.24
Sc	12.62 ± 0.65	12.77	12.12	12.31	12.78 ± 0.33	12.54	0.07	0.22
Fe %	3.73 ± 0.24	3.61	3.62	3.63	3.67 ± 0.11	3.60	0.04	0.06
Yb	2.70 ± 0.14	2.76	2.65	2.64	2.80 ± 0.10	2.73	0.03	0.35
Hf	4.11 ± 0.22	4.18	4.53	4.47	4.64 ± 0.12	4.70	0.08	0.31
Cs	6.47 ± 0.47	6.48	5.65	5.62	6.47 ± 0.34	6.27	0.17	0.72
Cr	89 ± 9	89	80	85	89 ± 5	84	1.5	5.0
Th	12.09 ± 0.54	11.73	11.86	11.77	12.14 ± 0.20	11.92	0.09	0.42
Eu	1.389 ± 0.072	1.399	1.330	1.390	1.425 ± 0.021	1.385	0.015	0.041
Rb	125 ± 9	115	146§	114	128 ± 9	119	7	15

\* The two entries for each element in a group are the average abundance and the root-mean-square deviation. The values are expressed in ppm or in percent if indicated after the element symbol. See table 2 for heading descriptions.

† True abundances are equal to listed values divided by the enhancement factor F.

‡ Value for one standard deviation.

§ The precision for this Rb value was 16 ppm rather than 7.

Table 5. Abundances\* of other elements or compounds measured by NAA or wet chemistry

Group or sherd: Number of sherds in group:	ARE 23	MML B 4	MML-14† F = 1.08	MML-15† F = 1.16	LOY 5	LOY-3
Ce	80.8 ± 3.0	56.8 ± 0.9	58.1	59.1	54.0 ± 3.6	70.0
Lu	0.402 ± 0.017	0.317 ± 0.022	0.345	0.350	0.328 ± 0.021	0.397
Ni	98 ± 15	58 ± 16	48	51	40 ± 11	52
K (%)	1.88 ± 0.31	1.48 ± 0.32	1.54	1.44	1.39 ± 0.18	1.42
Ba	435 ± 36	470 ± 26	496	594	731 ± 198	1217
As	6.5 ± 1.0	27.0 ± 3.9	31.3	31.8	25.9 ± 10.2	16.9
Sb	0.67 ± 0.07	1.42 ± 0.10	1.48	1.33	1.46 ± 0.40	
Zn	139 ± 7	85 ± 7	81	88	73 ± 8	91
CO <sub>2</sub> (%)‡	1.6 ± 1.2§			10.2	9.6 ± 1.9	3.8

Group or sherd: Number of sherds in group:	MML A 13	MML-16† F = 0.85	MML-3† F = 1.08	MML-2† F = 1.13	ATE 4	DIV-22† F = 1.09	Precision Accuracy
Ce	68.4 ± 3.8	68.6	68.9	68.8	70.5 ± 1.6	71.0	0.7 3.4
Lu	0.391 ± 0.025	0.412	0.432	0.425	0.395 ± 0.019	0.374	0.017 0.039
Ni	58 ± 15	67	77	46	56 ± 8	52	9 22
K(%)	1.82 ± 0.34	1.67	1.58	1.27	2.19 ± 0.20	1.73	0.21 0.28
Ba	415 ± 68	371	389	382	490 ± 105	771	13 24
As	15.1 ± 2.0	12.1	15.6	14.6	14.3 ± 2.8	12.5	0.7 2.5
Sb	1.25 ± 0.12	1.09	1.13	1.11	1.20 ± 0.10	1.52	0.09 0.10
Zn	83 ± 8	80	171	59	87 ± 12	243	5 5
CO <sub>2</sub> (%)‡	3.0§	1.1			0.8 ± 0.4	4.2	0.3 0.3

\* The two entries for each element in a group are the average abundance and the root-mean-square deviation. The values are expressed in ppm or in percent if indicated after the element symbol. See table 2 for heading descriptions.

† True abundances are equal to the listed values divided by the enhancement factor *F*.

‡ All CO<sub>2</sub> values are true values without any enhancement.

§ Six values only.

Table 6 Statistical comparisons of individual sherds with group averages from NAA

Range of deviation ( $\sigma$ ) Expected*	Numbers of elements in different ranges of deviation from group average				Reference Group	Group Assignment
	0-1 ~ 13	1-2 ~ 6	2-3 ~ 1	3-4 ~ 0		
ATE-1†	18	2			MML A	MML A
ATE-6†	16	3	1			MML A
ATE-8†	13	7				MML A
ATE-9†	15	5				MML A
DIV-22‡	17	2	1			MML A
MML-2‡	13	5		2		
MML-3‡	13	7				MML A
MML-16‡	16	4	1			MML A
MML-14§	15	5			MML B	MML B
MML-15§	13	6	1			MML B

\* Number of elements expected with different ranges of deviations from the group averages for a group member if the abundance distribution is Gaussian. Because enhancement factors were selected to optimize the agreement with the reference groups, the deviations from the group averages will generally be smaller than the Gaussian expectations. See table 2 for explanation of group and sherd designations.

† Abundances reduced by 4% to compensate for 4% average content of volatile material in MML A. Ate-1, -6, -8, -9 are individual Ateius signed sherds found in Strasbourg.

‡ See table 4 for enhancement factors.

§ See table 3 for enhancement factors.

the carbonate content of six of these sherds gave an average value of only 1.6% CO<sub>2</sub>, the Arretine sherds must have been well fired initially with essentially all of the carbonate destroyed.

After the present measurements were performed, an article by Banterla *et al.* (1973) appeared which contained NAA of a number of sherds of terra sigillata from Italy and Arezzo in particular. We cannot compare their work with ours since they did not give actual chemical abundances but instead ratios of gamma ray counting rates for different elements.

*Lyons pottery, La Mulette* Seventeen of the twenty-two sherds from La Mulette fall into two rather homogeneous chemical groups, MML A and MML B, which are quite suitable as reference groups for pottery provenience determinations (see tables 3 and 4). Comparison of the Fe and Al abundances in the fired and unfired samples of the same sherds indicate that group MML A contains ~4% volatile materials and MML B contains appreciably less.

Three other sherds have abundance values in the unfired samples which also correspond to the group composition patterns except all three appear to be diluted. The enhancements in abundances needed to make these sherds agree with the reference groups correspond closely to the abundances of volatile materials deduced from the Fe and Al abundances.

The presence of carbonate in the unfired MML-15 sample used for NAA was confirmed by wet chemistry which indicated 10.2% CO<sub>2</sub>. Thus, some sherds from La Mulette were either not well-fired originally or had absorbed CO<sub>2</sub> since then.

Table 7 *Sherd concordance*

<i>Sherd designations</i>	<i>Published* sherd no</i>	<i>Sherd designations</i>	<i>Published* sherd no</i>
<b>Pottery from Arezzo</b>		<b>Pottery from Loyasse</b>	
<i>Are group</i>		<i>Loy group</i>	
Are-2→4,7→10,15→17,19→24,	Same	Loy-1‡ (29)§	U†
		2 (30)	U
Are-27→29,32,33,35,37	U†	4 (32)	U
		5 (33)	U
<b>Pottery from Montée de la Muette</b>		6 (34)	U
<i>MML A group</i>		<i>Others</i>	
MML-3	33	Loy-3‡ (31)§	U
5	30		
16	38	<i>Ateius signed sherds</i>	
17	39	ATE-1	U
20	2	6	U
21	3	8	U
24	5	9	U
25	6	DIV-22	U
48	14		
59	25		
67	51		
69	53		
72	56		
94	71		
129	U		
<i>MML B group</i>			
MML-14	36		
15	37		
22	41		
23	4		
27	42		
135	U		
<i>Others</i>			
MML-2	32		

\* Picon *et al.* 1971.

† Unpublished.

‡ Sherd numbers used for NAA measurements only.

§ Sherd numbers used for XRF measurements only.

One sherd, MML-16, would be a member of group MML A if the abundance values were all reduced by 15% (see table 4). Part of this effect (~9%) can be attributed to the smaller amounts of volatile materials and Ca in MML-16, and the residual difference of ~6% may be due to additional SiO<sub>2</sub> in MML A or some other diluent which is not measured.

The remaining sherd from La Muette, MML-2, agrees in most respects with MML A if its unfired abundance values are all enhanced by 13% (see table 4). The elements U and Co, however, differ by over 3σ from the average values which may represent some local variation in the MML A composition.

*Loyasse* Five of the six sherds from Loyasse form a fairly homogeneous chemical group with an average  $\sigma$  of 8.6% for twenty elements, which is adequate for a reference group. Wet chemical analyses showed an average of 9.6% CO<sub>2</sub> in these five samples (see table 5) which indicated either the pots retained most of their carbonate after the original firing or absorbed CO<sub>2</sub> afterwards. One sherd from Loyasse, LOY-3, is somewhat different from the other five and probably reflects a local variation.

*Ateius* The four signed sherds from Strasbourg have abundances which form an extremely homogeneous group of twenty elements (table 3) with a  $\sigma$  of 3.8%. These sherds have  $\leq 1\%$  volatile material as determined from a weight loss measurement when fired to 1000°C. When the difference in volatiles ( $\sim 4\%$ ) is considered, these sherds are in excellent agreement with group MML A.

One signed sherd, DIV-22, from Lyons has NAA abundances which agree well with MML A if they are enhanced by 9% as shown in tables 4 and 6. Comparisons between the XRF and NAA measurements for Fe and Al indicate this sherd has 9% volatile material which is in moderate agreement with the 9% needed to make DIV-22 a member of MML A and the 4% volatiles in MML A.

Thus, all five of these sherds agree very well in chemical composition with sherds known to have been made at La Murette. The four sherds from Strasbourg not only are members of MML A, but may represent a subgroup as they agree in chemical composition with each other extremely well. DIV-22 and one of the members of MML A would fit into this subgroup.

In making up a chemical pottery group, there are often some arbitrary decisions taken: whether to add a sherd or two to the group (or conversely to remove one or two); whether to divide the group into subgroups in which each is internally more homogeneous than the larger group. Although one may justify the decision to make subgroups on the basis of statistics alone, there is some reluctance to be encumbered with subdivisions if they do not lead to some new insight. Attention is called to such a subgroup in this case because all five of the vessels with the Ateius signature fall within it. The reason for this may be quite trivial, but it seems worthwhile to keep a note of this occurrence pending further work on these wares which might illuminate the significance.

### *3.2. Comparison between the NAA and XRF measurements*

For a number of samples, definite discrepancies were observed between the XRF and NAA measurements, but these could almost all be attributed to differences in the sample preparation procedure. For those sherds with little or no volatile material, the agreements between the XRF and NAA determinations of the same elements were excellent, and the abundance values can be used to determine the differences in the calibrations used in the two measurements. This latter group of samples will be discussed first.

*Calibrations* If the abundances of the common elements for the groups ARE, MML B, and ATE, are weighted according to the number of sherds, the NAA values are higher than the XRF values for Fe, Al, Ti, K, and Ca by +3, -3, -10,  $\sim -2$ , and +2%, respectively. The results for Fe, Al, and Ca are consistent for the three groups within 1%, but those of Ti and K show larger variations. The Ti variation and at least part of that of K could just be due to the counting errors inherent in the measurements.

With the corrections given above, the abundance determinations of the two laboratories (with the exception of Ti and K) can be compared with only a 1% calibration uncertainty.

The NAA and XRF measurements discussed here can also be compared to others made with rocks of the United States Geological Survey (U.S.G.S.) as calibration standards. A number of these rocks were analyzed by the same NAA techniques as used for the present measurements (Bowman *et al.*). The abundance values for Fe, Al, Ti, and K were higher than the tabulated ones (Flanagan 1973) by +2, -3, -5, and -2 percent, respectively.

*Refiring pottery samples* Refiring samples prior to weighing is generally not necessary for determinations of provenience. If many elements are being measured and distinctive chemical groups have been determined, one selected element (or more) may be used to normalize the abundances without a significant loss in sensitivity for provenience assignments.

If only a few elements are being measured, however, the loss of one may be serious, and determining the abundance of the volatile components would be more desirable. Even with many elements being used in the analysis, chemical groupings made after such determinations would be more homogeneous generally and possibly permit better distinctions between similar chemical groups from different sites.

#### 4. CONCLUSION

Pottery with the Ateius signature has been shown to have the same chemical composition pattern as many pottery rejects found near kilns in the large complex of workshops of Montée de La Muette in Lyons. We believe this indicates definitely that the great pottery-making firm in Arezzo, Ateius, had a branch workshop in Lyons around 10 B.C. This branch was probably opened with experienced workers and equipment from Arezzo in order to shorten the distance to the new markets of Gaul and the Germanic border legions.

Further measurements of the same type may give information on the extent of the diffusion of pottery from Lyons workshops into Gaul and Germany and identify additional branch workshops of the firm of Ateius.

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