NEW MYCENAEAN POTTERY PRODUCTION CENTERS FROM THE EASTERN PART OF CENTRAL GREECE OBTAINED BY NEUTRON ACTIVATION ANALYSIS

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Abstract: Neutron activation analysis results of a set of more than 120 sherds and whole vessels including misfired pieces from Locris, Phthiotis and Southwestern Thessaly are presented. The material covers the time period Middle Helladic to Late Helladic IIIC. Several new patterns are detected, some of which can be assigned with high probability to that region. A special result concerns several fragments of pictorial craters depicting ships and sea battles found in LHIIIC Middle levels at Livanates-Kynos. As suggested by our data they originate from a manufacturing place in Eastern Locris.

Introduction:

Since the mid-80ies our archaeometry group is working on a project concerning the classification and provenance determination of Aegean Bronze Age pottery which has been a focus of archaeological interest for more than a 100 years. Of all the different pottery classes used during the Bronze Age, special attention was paid to the fine decorated pottery of the Greek Mainland and adjacent regions. The period of the Late Bronze Age, the Mycenaean period, is especially well investigated, and this for the following reasons:

Mycenaean decorated pottery shows a well defined range of vessel shapes and motives so that even the smallest fragments can be attributed with certainty to specific vase types. It is very homogeneous in appearance over wide areas and it has a wide distribution, encompassing almost the whole Mediterranean. The archaeological questions arising immediately are:

1. How centralized was the production? That is to say, was this pottery manufactured in only a few places and distributed by trade to the different regions where it is found today. Or was its production rather decentralized and organized by potters imitating the shapes and decorations on demand by the customers during this time? These questions especially apply to Mycenaean vase painting of the highest quality, like the Pictorial Style.

2. Was there some sort of internal ranking between production places of only regional and such of supra-regional importance? If this were the cases, could it be,

that the workshops connected with the Mycenaean palaces, especially in the Argolid, were the most important ones?

To answer these questions by archaeological means, tentative assumptions can be obtained for example by considering distribution patterns of pottery shapes or styles. As is generally agreed today, compositional information obtained by natural scientific methods will lead to new insights and either corroborate or contradict these assumptions, but also add new questions, for example

3. If in addition to a between sites compositional variation also a variation within a site is detected (i. e. a sub-group pattern), can these subgroups stylistically or typologically be characterized and related to a technological tradition or change? Are they related to specific production techniques for different customers or use?

Neutron Activation Analysis(NAA) method and principles of chemical provenancing

To determine the composition of pottery NAA is known to be especially well suited, since its properties fulfill all the special demands very well. About 30 elemental concentrations per sample are measured routinely in our laboratory with the help of an automated sample changer and an elaborate spectrum evaluation program(Mommsen et al. 1995 and references therein). It is a modified version of the former procedure of Berkeley described by Perlman and Asaro(1969). Our results can be directly compared to published Berkeley (and Jerusalem) data, since we calibrated our Bonn standard against the Berkeley pottery standard. Now we have about 1750 samples of Bronze Age pottery of Greece in our data bank. Some 1000 more samples are still awaiting analysis and the work will continue.

First the principles of ceramic provenancing by elemental analysis will shortly be summarized pointing out especially what progresses have been made in interpretation of the data. As long as the clay, the raw material for production, was not traded, the elemental pattern measurable in ceramics is characteristic for a certain *production series* of a pottery workshop at a certain place. Once this pattern is known, e. g. by measuring so-called reference material, that is material which is produced locally with a high probability, all pieces of unknown production place having this elemental pattern can be assigned to that origin.

As members of a production series we define simply all pieces which analyse the same. This is a 'reductionist' approach, as Pollard and Heron wrote(1996, p. 107), but it has the advantage, that it is free of any possibly misleading interpretations and, if used as a first working hypothesis, results in given facts, especially, if stringent rules for chemical similarity are applied. This similarity in many elemental concentrations is an indication, that the ancient potters did not change anything during the manufacturing process, or at least, to be precise, that no change occurred which influenced the concentrations of the elements measured. If a new clay or clay mixture was used, or if a new clay refinement technique was applied, a new pattern of elemental values may show up, a second pattern pointing also to this production place is produced. Thus, there may be many different patterns for each production place. Therefore, the finding of a different pattern in pottery from the same site does not necessarily mean that we are dealing with products produced somewhere else, we might have found just a second production series at the same place. This is often experienced, if material of different type is analysed which was manufactured probably on purpose with a different 'recipe'. For instance, in Roman vessels produced contemporaneously about 2000 years ago in the same pottery workshop in Bonn, we detected 2 different patterns(Mommsen et al., 1994) occurring in different vessel types. We believe, that the ancient potters of that workshop in Bonn used different 'recipes' in the production of these vessels, they already optimized their procedures to satisfy quality or market demands. But with certainty both patterns are characteristic for the production in Bonn.

One of the main problems in provenancing pottery is the availability of reference material, since for these 'control samples' the production place has to be known beforehand. Rather secure are kiln wasters found in the vicinity of a potters kiln. But, during the Mycenaean period, only very few potters' kilns have been detected on the Greek Mainland and these kilns only rarely yielded misfired pieces. In such a situation one has to rely on archaeological results which might introduce a bias from the beginning. Therefore, only the analysis of a very large number of samples will allow reaching well founded conclusions.

Importance of precision of measurement and best relative fit

Another crucial point in provenancing is the quality of the measurements performed. In order to classify pottery by its elemental composition as many elements as possible have to be measured with a high precision which is a difficult task for trace elements. That good measurements with high precision are needed is not astonishing, since all ceramic material contains more or less similar elemental abundances. We will demonstrate this on a newly detected group of 42 sherds representing a production series from a pottery workshop or district probably in Eastern Locris and quite possibly even in the coastal settlement mound called 'Pyrgos Livanates' which can be identified with Kynos, according to Homer the home of Ajax (Dakoronia 1993a). The group contains, too, all the samples from pictorial craters depicting Mycenaean war ships (see below). In Tab. 1 the average concentrations M in percent or ppm are listed together with the spreads sigma (= root mean square deviations). The third column expresses the spreads in percent of the average values. As can be seen, for many elements spreads of less than 5 % are obtained. As example for an element measured with such a precision Fig. 1 shows the single raw data of La for the 42 sherds of this group. Per definition about 2/3 of all the values lie inside a range of M $\pm$ sigma. There is only one outlying sample which, for now, is assigned to this group, because all the other elemental values fit, but may be found to be a member of a subgroup, if more samples are analysed.

The discrimination can be brought into still a better focus by a best relative fit of the data. This is similar to the consideration of elemental concentration ratios instead of the concentrations directly and corresponds to the reduction of the degrees of freedom by 1, which is not harmful because of the many elements measured. The effect of such a best relative fit to the data of the group Locris-l is shown in the following columns of Tab. 1 and for the element La in Fig. 2. The average values M are more or less unchanged, but the spread values decreased enhancing the possibilities of discrimination. The reason for this is, that, on the one hand, all experimental errors lowering or raising all the values by constant amounts due for example to weighing errors or to neutron flux inhomogeneities cancel and that, on the other hand, dilution effects of the clays by additions of slightly varying amount of e. g. sand are corrected at the same time. Now we perform always such a best relative fit during the group formation to obtain sharper patterns.

In Fig. 3 the distribution of all the La values in our Greek databank is shown together with the distributions of the group Locris-1 and of the most dominant group in Greece called Mycenae-Berbati. The La values in the Greek pottery analysed so far cover only a rather small concentration range from about 20 ppm – 45 ppm. A similar small range is found for many other elements. To discriminate different production series, the large number of measured elements helps, but a precision of measurements as high as possible is needed, too, as demonstrated by the example of the La data.

Groups of samples with similar composition are determined by our own search method which is a filter method sorting out from a data bank of concentration values all samples with similar composition. A new similarity measure which we call modified Mahalanobis distance performs this task very effectively(Beier and Mommsen, 1994). It is able to consider not only individual experimental errors and correlations, but corrects also for the constant shifts of the data, so that diluted samples are not missed during the filtering.

Choice of samples from central Greece and NAA results

In general, analytical data of Bronze Age and especially Mycenaean ceramics from the central part of Greece are rare. Only a few analyses done by the Fitch Laboratory of the British School at Athens exist(Jones 1986). Our 123 sampled vessels and sherds which cover the time period MH–LHIIIC originate from excavations conducted by the 14th Ephorate of Antiquities under the direction of Ph. Dakoronia in Eastern Locris, Achaia-Phthiotis and also in Southwestern Thessaly. The bulk of the samples, however, is Late Mycenaean in date and comes either from chamber tombs (Livanates-Kokkinonyzes, Livanates-Rema Pharmaki, Kolaka-Agios Ioannis, Megaplatanos-Sventza, Atalanti-Spartia, Tragana)(Dakoronia 1980, 1985, 1990, 1992, 1993b) or the settlement site of Livanates-Kynos in Eastern Locris. Excavations in the NW part of the hill of Livanates-Kynos since 1985 yielded an extensive building complex of the LHIIIC period which evidently was used for storaging purposes. In addition to these storage facilities this area during LHIIIC Middle was also linked to pottery production, since in 1993 a potters' kiln was uncovered. Apart from the architectural remains the most conspicuous finds from the LHIIIC Middle levels at Livanates-Kynos are fragments of craters with a rich pictorial decoration consisting of ships and sea battles(Dakoronia 1987, 1988, 1996) since this is the earliest evidence for this artistic genre in the history of Greece.

The number of samples per site and the find-spots themselves are listed in Tab. 2 together with the grouping results. The NAA concentration data (average values and spreads) of the main groups are given in Tab. 3. As grouping result of the new set of samples a picture already known to us emerges. Besides about 10 % chemical loners many different new groups, some with only a few members, can be distinguished. We will not discuss all these sometimes still quite small groups. The total number of Bronze Age Greek groups distinguishable until now in our databank increased to over 80, but due to the lack of good reference material only a very limited number, at the time being only 8, can be assigned with high probability to definite production places.

Since the samples from Central Greece under investigation include several misfired pieces and sherds from the area of the kiln at Livanates-Kynos, we expected to find new groups assignable to that place. In fact, the hitherto unknown main group named Locris-l of 42 pieces already used as example above could be added to the list of located patterns. It is present not only in Kynos itself, but traceable in several other sites in Eastern Locris thus indicating a more than only locally limited importance of this workshop.

The other smaller groups Locris-m and Locris-n have wasters as members too, so we assume that they are locally produced as well representing a different workshop or a different production series of the same workshop. Compared to the group Locris-l the group Locris-m (Locris-n) has much higher Co, Fe and Ni (La and Rb) values.

The main 2 new groups Locris-l and Locris-m having more than 15 members are depicted in Fig. 4 together with formerly detected patterns of Bronze Age Greece of presumingly known location. Shown in Fig. 4a is a result of a discriminant analysis of 450 samples assuming 8 groups. Taking only the samples of the cluster of 5 groups in Fig. 4a the result Fig. 4b is obtained. As can be seen, the new Locris groups are well separated from the other groups. Still overlapping groups in the plots of discriminant functions W1 and W2 are resolved in diagrams of the higher order functions. The group Knossos/Phaistos-1(KP-1) published by Mommsen et al. (1994) can be distinguished from the group Locris-l mainly by its lower Hf and higher Ni values, group KP-2 also tentatively assigned to Crete has lower Cs and Sc concentration values.

Discussion

The dominant group in our set of vessels and sherds of Central Greece Locris-l is of special interest, since all of the 11 sherds of craters depicting ships belong to it. This means that we are dealing with a distinct school of Pictorial Vase Painting which was located in Eastern Locris as suggested by our archaeometric data. Up til now the only workshop of Pictorial Vase Painting in Greece which was defined by finds of wasters(Akerström 1987, see below) is located in the Argolid near Mycenae exporting its products, as could be archaeometrically proven, to Cyprus and the Levant. Another workshop known to have produced pictorial craters during that phase was situated most probably in Kouklia in Cyprus as NAA data from Berkeley show(Karageorghis 1973). More archaeometric results concerning these high quality pictorial vessels should be obtained.

Another noteworthy result concerns the analysis of 5 matt-painted vessels - mostly beaked jugs - belonging to the so-called Delta-1-beta type which is characteristic for the

Middle Helladic(MH) Period in Phocis, Achaia-Phthiotis and parts of Thessaly(Wace and Thompson 1912, pp. 180–185; Maran 1992a, pp. 151–156, 286, 313–318, fig. 24, cf. pls. 50,9; 64,3; 122,7; 144,7). Although found at 3 different find spots in Southwestern Thessaly and the Sperchios Valley they apparently are all produced at the same workshop and therefore point to exchange networks operating in these regions during the MH. Moreover, since beaked jugs with virtually identical features are found as far south as Kirra in the region of Delphi, the question arises, whether these matt-painted jugs were even exchanged over the high mountain barrier separating the Sperchios Valley from Southern Phocis. To answer these questions samples of these jugs from Kirra thanks to the courtesy of Dr. D. Skorda were included in the program in 1995, the analysis of which is still underway. In the absence of reference material, the point of origin of the Delta-1-beta type cannot be established, and thus the direction of the exchange, whether from north to south or vice versa, is not certain. However, it has to be pointed out that the possibility emerges that during the MH Period in Central Greece there existed pottery production centres distributing their products over a wide area, a situation comparable to the Aiginetan workshops producing the Gold Mica Fabrics(Maran 1992b, pp. 179–214).

Meanwhile not surprising to us is the presence of a large group of 18 sherds (MB-Locris) having the well known pattern named Mycenae-Berbati(MB)(Mommsen et al. 1995). At many Greek sites this set of concentration data is detected in sherds spanning the time period from the MH- to the LH IIIC phase and even to Corinthian sherds of the classical period(Bonn, unpubl. data). This pattern is tentatively assigned to a workshop in the Argolid near Mycenae because of several wasters measured by Perlman and Asaro having this pattern and found in the excavations of a Mycenaean kiln site in Berbati(Akerström 1987) which also produced the pictorial vases mentioned above. NAA detects the MB pattern, too, in most of the pieces exported to the Eastern Mediterranean and even in one sherd brought to Spain. The NAA result, therefore, here too favors an assignment of the 18 sherds found in Locris to an Argive origin. For most of the sherds of this group an import to Locris would not be contradicted on archaeological grounds. But a misfired or secondary fired, vitrified sherd of a large pithos or even of a roof tile from the kiln at Livanates-Kynos, a piece normally to be rated as local, has also pattern MB. Furthermore, a few members of this new set of vessels, e. g. 2 monochrome red burnished piriform jars, do not have any comparison in the Argolid. This is mentioned, since in a recent investigation of Boeotian Late Bronze Age ceramics by Tomlinson (1996) discussing old NAA results of the Berkeley group the pattern MB was also found in pottery which by archaeological reasoning was not regarded as of Argive origin. Further work on different ware types and from different regions has to be done to clarify this still open question concerning the provenance of the overabundant MB pattern in Greece. The occurrence of a pattern which is similar in so many elements at two different production places is very improbable. But a near similarity of a pattern (except for the element As normally not considered in provenance studies) has been already detected in typical vessels from Troia which analysed like the MB material(Knacke-Loy 1994 and our own unpublished data). We are eager to obtain the results of the many samples taken already at Thebes due to the courtesy of Dr. Aravantinos to further investigate this question.

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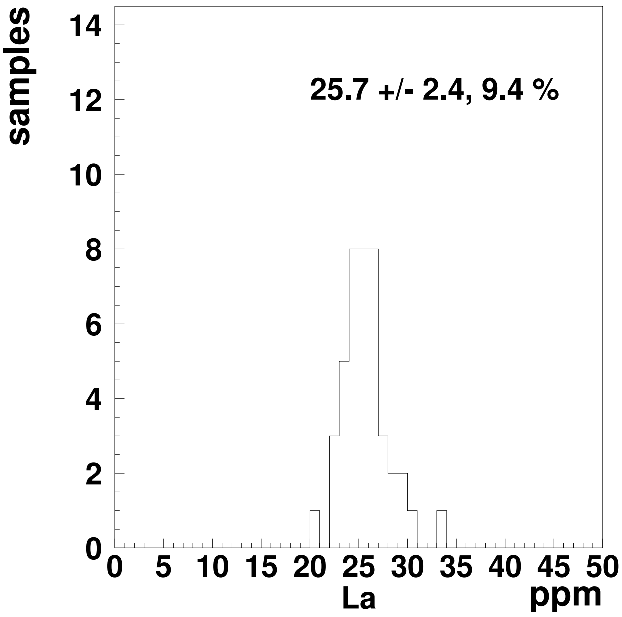

Figure 1: Distribution of La concentration values in ppm: raw NAA data of group Locris-l of 42 samples. The average La concentration and the spread is given.

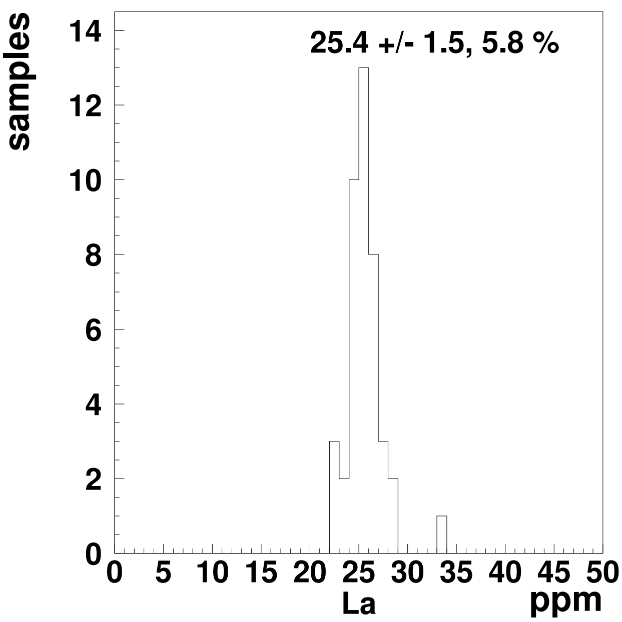

Figure 2: Distribution of La concentration values in ppm as in Fig. 1: NAA data of group Locris-l after best relative fit showing the decrease of the spread.

Table 1: Concentrations of 30 elements: averages M and spreads sigma in ppm if not indicated otherwise. The average statistical error of a single measurement is given for comparison.

	group Locris-l (42 samples) raw data				group Locris-l (42 samples) after best rel. fit				aver. stat. error
	M	±	sigma	%	M	±	sigma	%	%
As	7.70	±	5.62	73.	7.68	±	5.63	73.	1.1
Ba	399.	±	105.	26.	388.	±	86.	22.	8.9
Ca%	6.89	±	2.04	30.	6.88	±	2.06	30.	6.0
Ce	57.7	±	4.2	7.2	57.4	±	2.8	4.8	0.9
Co	29.1	±	3.3	11.	29.0	±	3.0	10.	0.5
Cr	386.	±	40.	10.	384.	±	34.	8.8	0.5
Cs	11.8	±	2.8	24.	11.8	±	2.8	24.	0.9
Eu	1.09	±	0.08	7.3	1.09	±	0.06	5.7	2.3
Fe%	5.23	±	0.28	5.3	5.21	±	0.28	5.3	0.4
Ga	20.2	±	2.6	13.	20.1	±	2.6	13.	8.6
Hf	4.41	±	0.37	8.4	4.40	±	0.34	7.8	1.7
K %	2.16	±	0.20	9.1	2.15	±	0.17	8.0	1.2
La	25.7	±	2.4	9.4	25.4	±	1.5	5.8	0.3
Lu	0.45	±	0.08	17.	0.44	±	0.04	8.5	4.6
Na%	1.03	±	0.17	16.	1.03	±	0.17	16.	0.6
Nd	22.3	±	2.5	11.	22.3	±	2.2	10.	10.
Ni	316.	±	29.	9.3	314.	±	24.	7.5	3.3
Rb	115.	±	8.	7.4	115.	±	6.	5.6	2.0
Sb	0.54	±	0.10	18.	0.54	±	0.09	17.	13.
Sc	22.4	±	1.0	4.3	22.3	±	0.9	4.1	0.13
Sm	4.45	±	0.42	9.4	4.43	±	0.35	7.9	0.5
Ta	0.84	±	0.05	6.4	0.84	±	0.04	4.6	3.2
Tb	0.64	±	0.07	11.	0.64	±	0.07	10.	6.9
Th	9.85	±	0.57	5.8	9.81	±	0.36	3.6	0.7
Ti%	0.42	±	0.07	16.	0.42	±	0.07	16.	6.4
U	2.29	±	0.33	14.	2.25	±	0.23	10.	3.0
W	1.77	±	0.22	12.	1.76	±	0.20	11.	7.1
Yb	2.54	±	0.14	5.6	2.53	±	0.10	3.9	2.3
Zn	98.4	±	12.5	13.	97.9	±	10.6	11.	2.3
Zr	195.	±	28.	14.	194.	±	28.	14.	14.

Table 2: Overview of grouping results of 123 sherds from Eastern Locris, Phthiotis and Southwestern Thessaly, distribution of the sherds into the NAA groups (L-l = Locris-l, L-m = Locris-m, L-n = Locris-n, Phth = MH matt-painted jugs, MB = Mycenae-Berbati, s = chemically ungrouped single)

archaeological groups	NAA groups												sums
	L-l	L-m	L-n	6 other groups						Phth	MB	s	
Eastern Locris													
Atalanti	1										1		2
Kolaka				2							2		4
Livanates (Kynos and chamber tombs)	35 (+3?)	11	4	1		2					9	11	76
Megaplatanos	3	2			1								6
Tragana	3	5		1	1		4	2	3		6 (+1?)	4	30
Phthiotis and SW-Thessaly													
Achinos										2			2
Neo Monastiri										1			1
Perivoli Spercheiados										2			2
total no of sherds in NAA groups	42 (+3)	18	4	4	2	2	4	2	3	5	18 (+1)	15	123

Table 3: Concentrations of 30 elements of the 4 main groups of Eastern Locris, Phthiotis and Southwestern Thessaly and of the group Mycenae-Berbati(MB): averages M and spreads sigma in ppm if not indicated otherwise, corrected for dilution

	Locris-l 42 samples		Locris-m 18 samples		Locris-n 4 samples		MH-jugs 5 samples		MB-Locris 18 samples		MB-total 326 samples	
El	M	σ in %	M	σ in %	M	σ in %	M	σ in %	M	σ in %	M	σ in %
As	7.68	73.	5.17	26.	8.82	59.	6.92	28.	7.68	98.	6.17	55.
Ba	388.	22.	334.	20.	379.	14.	596.	72.	406.	26.	405.	29.
Ca%	6.88	30.	5.63	31.	4.30	16.	0.78	28.	8.10	42.	9.45	23.
Ce	57.4	4.8	47.2	5.3	69.5	4.2	74.6	5.4	62.8	2.6	62.5	2.5
Co	29.0	10.	50.5	7.1	31.2	4.6	24.6	20.	28.7	10.	28.1	6.9
Cr	384.	8.8	671.	18.	360.	8.9	247.	6.0	258.	9.9	249.	11.
Cs	11.8	24.	5.68	12.	7.25	4.0	7.14	2.6	8.89	19.	8.68	10.
Eu	1.09	5.7	0.87	5.7	1.20	3.4	1.30	2.1	1.11	4.5	1.14	4.5
Fe%	5.21	5.3	6.07	4.3	5.42	2.0	5.62	3.5	5.30	4.1	5.17	3.6
Ga	20.1	13.	19.8	11.	23.9	6.3	24.3	6.6	23.6	12.	21.3	26.
Hf	4.40	7.8	2.96	11.	3.78	6.2	5.66	8.4	3.84	14.	3.60	9.8
K %	2.15	8.0	2.08	11.	2.98	8.9	2.06	6.4	2.52	12.	2.58	11.
La	25.4	5.8	21.6	5.0	32.3	3.4	33.9	2.7	29.8	4.8	31.3	3.1
Lu	0.44	8.5	0.41	30.	0.60	48.	0.83	43.	0.61	65.	0.42	6.3
Na%	1.03	16.	0.54	23.	0.69	40.	1.09	18.	0.73	41.	0.60	35.
Nd	22.3	10.	17.6	12.	27.7	13.	30.0	8.0	24.2	10.	26.0	5.9
Ni	314.	7.5	787.	11.	325.	7.5	134.	14.	228.	17.	215.	13.
Rb	115.	5.6	114.	10.	152.	3.1	139.	4.2	146.	10.	148.	8.9
Sb	0.54	17.	0.55	19.	0.74	41.	0.61	12.	0.59	14.	0.59	16.
Sc	22.3	4.1	21.2	4.5	21.9	2.1	22.5	5.2	22.1	3.5	21.3	4.3
Sm	4.43	7.9	3.40	5.4	5.18	1.9	6.08	6.1	4.63	6.4	4.88	4.2
Ta	0.84	4.6	0.69	7.4	0.90	3.0	0.99	5.8	0.83	7.4	0.80	6.6
Tb	0.64	10.	0.49	9.0	0.76	6.9	0.85	7.4	0.64	7.5	0.66	9.1
Th	9.81	3.6	8.43	4.8	11.5	4.1	13.5	4.9	11.1	3.4	10.9	2.9
Ti%	0.42	16.	0.35	17.	0.47	14.	0.44	5.5	0.38	15.	0.44	19.
U	2.25	10.	1.68	5.4	2.30	4.3	2.80	5.5	2.34	9.3	2.30	6.1
W	1.76	11.	1.39	12.	1.96	6.1	2.28	5.6	1.94	9.8	2.14	17.
Yb	2.53	3.9	2.06	4.3	2.71	3.1	3.06	4.1	2.62	3.3	2.60	3.4
Zn	97.9	11.	104.	6.9	110.	6.6	103.	4.1	106.	9.0	111.	12.
Zr	194.	14.	155.	18.	170.	16.	252.	20.	178.	23.	157.	20.

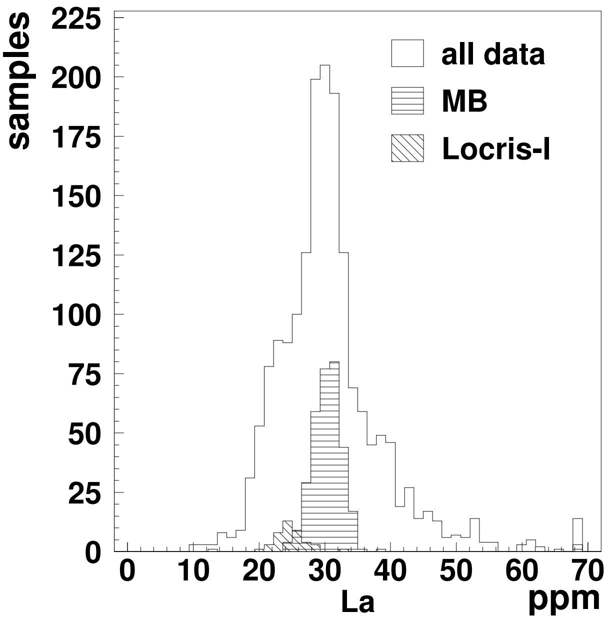

Figure 3: Distribution of La concentration values in ppm: raw NAA data of total Greek databank (1750 samples) and of the groups Locris-l (42 samples) and Mycenae-Berbati (326 samples)

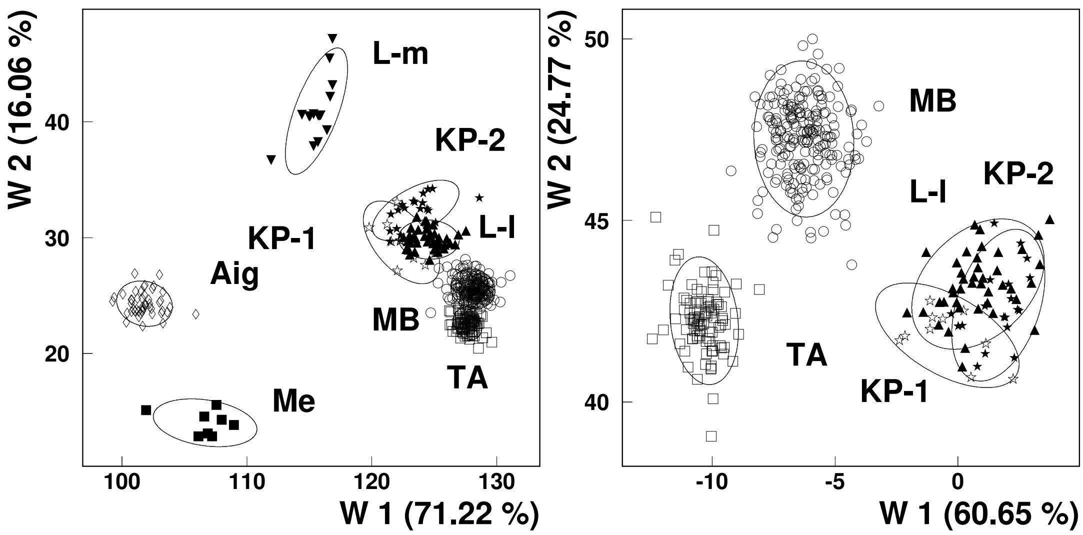

Figure 4: Discriminant analysis of a) 450, b) 378 samples of Greek Bronze Age Pottery assuming a) 8, b) 5 groups (L-l = Locris-l, L-m = Locris-m (a only), MB = Mycenae-Berbati, TA = Tiryns-Asine, Aig = Aigina (a only), KP-1, -2 = Knossos-Phaistos-1, -2, Me = Melos (a only)). Plotted are the discriminant functions W1 and W2 which cover in a) 71 % and 16 % and in b) 61 % and 25 % of the between group variance. The ellipses drawn are the 2σ boundaries of the groups.