Production Sites of EIA Greek Bronze Tripod Cauldrons - First Evidence from Neutron Activation Analysis of Casting Ceramics

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ABSTRACT

Bronze tripod cauldrons were one of the most prestigious types of objects in Greece during the Early Iron Age (EIA). Because of its character as an exchange object with a value easy to assess, the tripod was fit to become an attribute used in the communication of personal status. Consequently, the find distribution of tripods can be used to identify hotspots of elitist interaction.

Fortunately, quite a lot of the extant tripod fragments have a clay core and/or show preserved residues of the casting moulds on their surface. In our pilot study with 61 samples from Olympia and 5 samples from Kalapodi it is shown that Neutron Activation Analysis (NAA) allows a coherent internal chemical grouping of the clay pastes used in the ancient casting workshops. Furthermore, comparative material from workshop debris and also geological samples allow a geographical localisation of many of the chemical groups. Generally spoken, NAA therefore seems to be an effective method to define production sites of artefacts cast in the lost wax technique. In the case of Early Iron Age tripods, sites and travelling-routes of workshops can be traced as well as travelling routes of customers. This provides new hard data for modelling both the political and the economic structures of EIA Greece.

INTRODUCTION

The present study investigates the provenance of tripod cauldrons on the basis of the residues of casting ceramics still adhered to the bronze fragments (Figure 1).

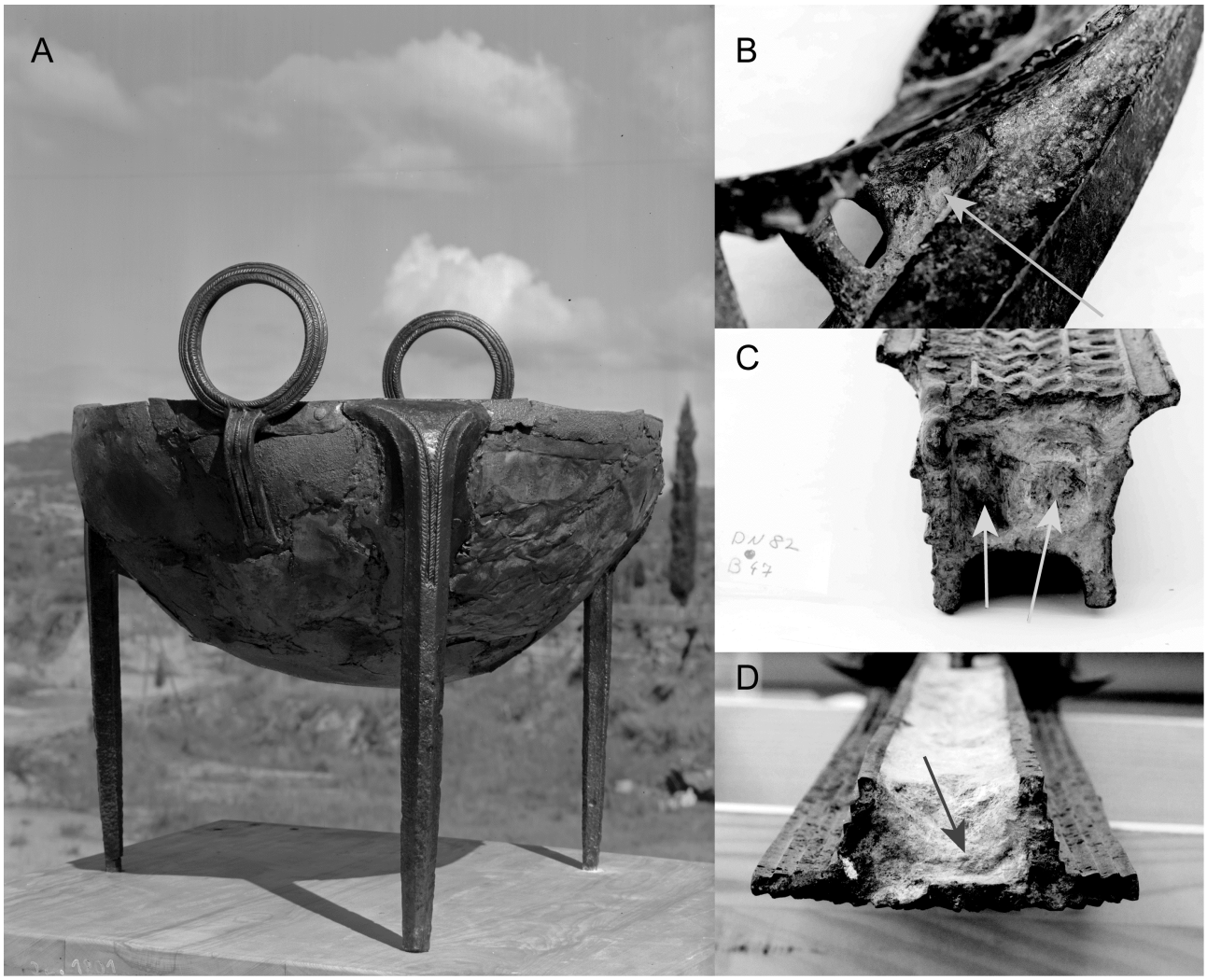

Figure 1: Examples of bronze tripod cauldrons and residues of casting ceramics.
A: Tripod Olympia Inv. B 1240, belonging to chronological phase 3 (ca. 975-925 BC). H. of rim 50 cm. Not sampled.
B: Detail of a tripod leg excavated at Kalapodi, with scant residues of the casting mould (sample KalGM 100). Phase 3 (ca. 975-925 BC).
C: Fragment of a tripod leg excavated at Olympia, with two clay cores (sample OlyGM 1 core). Phase 5 (ca. 850-800 BC).
D: Fragment of a tripod leg of "Gratbein"-type excavated at Olympia. Restored weight of leg ca. 30 kg. On the back side abundant residues of the casting mould (sample OlyGM 9). Phase 7 (ca. 750-700 BC).

The underlying assumption is that the clay for the preparation of the pastes was collected in the vicinity of the workshops. Additionally, and in order to establish a sound background for the provenance study, we aim at understanding the technical properties of the casting ceramics and the production process.

Tripod cauldrons (henceforward: tripods) were an important object class in Early Iron Age (EIA) Greek society. They were used for the boiling of meat at communal feasts and for preparing hot water for bathing and were thus embedded in conspicuous consumption. Due to their evident

material value, they also played a role as exchange objects and prestige goods. This eventually resulted in the custom of dedicating tripods to the gods, a practice which is observed in a certain range of sanctuaries in EIA Greece (Figure 2).

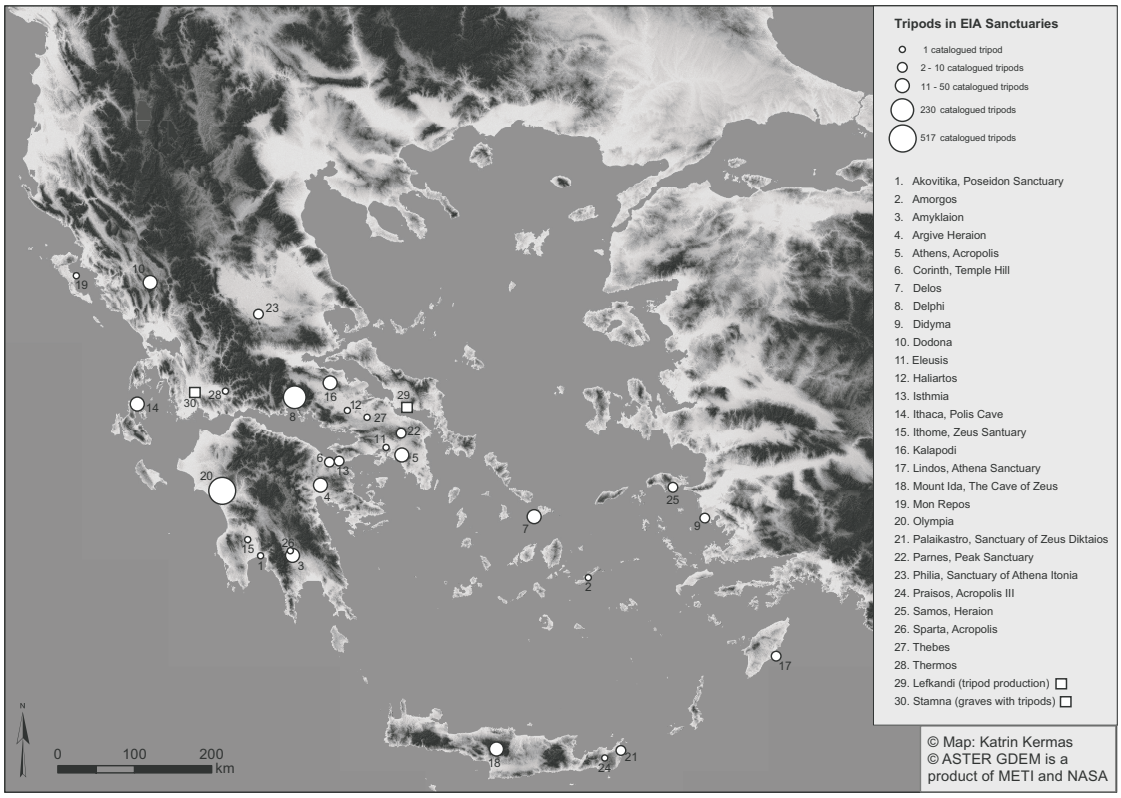

Figure 2: Sanctuaries with dedications of EIA tripod cauldrons (round symbols), and other sites mentioned in the text.

The find distribution between these sanctuaries is highly significant indicating that dedications of tripods concentrated on sanctuaries that served as central meeting places of a politically active elite (Kiderlen, 2010, 91–98 with references). Consequently, archaeological inquiry can use tripods as indicators for the political activities of this elite as well as for the economic structures of the period.

Greek tripods are well suited as a study object since:
1) the number of tripod finds is high (fragments belong to about 970 catalogue numbers),
2) manufacture of tripods involved a wide scale of technologies including both casting and hammering,
3) metal weights are high (reconstructed weight per tripod: between c. 6 and 30 kg, in some cases even 100 kg),

4) chronological resolution is good. The typological sequence and its links to ceramic chronology are reliable meaning that most of the tripods can be assigned to one of eight chronological phases in the time span between c. 1200 and 700 BC (phases 0–7),
5) in most cases find spots are documented,
6) archaeometric investigation potentially provides further spatial data, mainly:
– the provenance of the copper ores and smelting sites (Lead Isotope Analysis (LIA)); chemical bulk analysis; metallography (Kiderlen et al., forthcoming))
– the provenance of the casting workshops (NAA of residues of casting ceramics adhering to the bronze fragments; see below)

Nakoinz (2013) reviewed theoretical models for the socioeconomic interpretation of spatial patterns of interaction. Evidently, the capacities of any interpretative model of this sort are much enhanced if not only find spots, but also hard data on provenances can be included.

Internal typological grouping and chronology of the investigated tripods will not be discussed here in detail, but a general idea is given in table 1: Tripods DN 12, 772, 1163 and 10158 are the earliest sampled tripods. Their legs are late versions of so called "massive legs" with prismatic sections and belong to phase 3 (Figure 1 a,b). The dates given by Maaß (1978, 6–7; 110; 228), Rolley (1977, 105–113) and Felsch (2007, 30–37) for tripods like these are much too late. They should be dated well before 900 BC, as is proven by new grave contexts in the area of the river Achelous in Aetolia (Christakopoulou–Somakou, 2009, cat. T378; Stavropoulou–Gatsí et al., 2012; Kolonas & Kiderlen, in prep.). Stratified workshop dumps in the settlement at Lefkandi on Euboea (Janietz, 2001, 18-20; Kiderlen, 2010, 100-102) give a terminus ante quem around 900 BC for the first legs with rectangular or Pi-shaped sections that become frequent in phase 4. Most of the sampled tripods of phase 6 have legs decorated in the matrix technique (underlined in Table 1) as defined by Maaß (1978, 34–39; 48–58). All sampled tripods of phase 7 have legs decorated with vertical scales (Figure 1 d; bold in Table 1) and belong to the "Gratbein"-Type as defined by Maaß (1978, 48-62) as well.

All of the tripods sampled within the present study originally consisted of six main parts (Figure 1 a): the basin, which is hammered out of one single piece of copper alloy ("bronze"), the three legs and two handles. Legs and handles were separately cast of bronze in the direct version of the lost wax technique and riveted to the basin. In the direct version of the lost wax process, objects were modelled with wax down to every detail. The wax model then was first encased in clay and afterwards removed by heating or firing the clay mould (Zimmer, 1990, 13). Finally, the resulting

hollow space was filled with the melted bronze. After the casting the ceramic mould was broken apart uncovering the final bronze object, which still had to be cleaned from remains of the casting ceramics.

Commonly, different layers of clay were applied on the wax model with a particularly fine–grained first layer, which itself can consist of different thin strata which had been applied with a soft brush (Schneider & Zimmer, 1984). In the present study, mainly residues of this first layer were examined and in some cases clay cores from the centre of the legs as well.

METHODS AND MATERIAL STUDIED

Sample Selection and Sampling

The Zeus sanctuary of Olympia is by far the most important site for EIA tripods manufactured in the direct lost wax process. More than 1000 fragments belonging to about 420 catalogue numbers are preserved. The sanctuary of Apollo near the modern village of Kalapodi in central Greece is one of the sanctuaries that directly follow Olympia and Delphi, counting 19 catalogue numbers. From the assemblages of Olympia and Kalapodi those bronze fragments were investigated, which revealed apparent remains of casting ceramics. These remains can typically be found on the inner edges of the backside of the legs, which were not visible and for this reason were not always entirely cleaned by the ancient artisans. For methodological reasons, multiple samples from one tripod were taken in some cases. This resulted in the selection of 66 samples from 64 fragments belonging to 48 different tripods. Olympia is represented with 61 samples from 59 fragments belonging to 43 different tripods. Kalapodi is represented with 5 samples from 5 fragments of 5 tripods (Table 1 and Supplementary Table 1). In each case powdered samples of c. 100–200 mg of the remains of the casting ceramics were taken using a pointed tungsten carbide drill. In some cases it was also possible to sample a small fragment, typically with a size of c. 1 to 2 mm, by using a scalpel.

As comparative material, we selected 20 samples of metallurgical and other technical ceramics from workshop contexts and secondary contexts at Olympia, and 18 samples of metallurgical ceramics from workshop contexts at Kalapodi (Table 2). While the tripods sampled for this study date

between ca. 975 and 700 BC, the comparative material both from Olympia and Kalapodi dates between ca. 550 and 300 BC. Contemporary material does not exist in sufficient numbers. However, the selected comparative material provided good information about raw materials and recipes used at these sites for the fabrication of technical ceramics. For further contextualization, the results were also compared with the Bonn NAA database of pottery.

Analytical Approach

The analytical approach was constrained by the scarce amount of preserved casting ceramics, that were available for sampling (Figure 1 b). For example, this precluded the application of ceramic petrography, which has been applied in former studies on casting ceramics (Reedy 1991, Lombardi and Vidale 1998, Schneider 2004, Goren 2008, Lombardi 2009). Therefore, this investigation of provenance follows an alternative approach based mainly on the examination of the trace element composition of the casting ceramics (Holmes & Harbottle 1991). The analyses are complemented by microstructural examination and infrared spectrometry.

Neutron Activation Analysis (NAA)

The NAA procedure applied in Bonn is able to measure about 30 minor and trace elements in fired-clay objects, many with low experimental uncertainties of one or a few percent only. This results in unique concentration patterns of clays from different geographical locations that are easily distinguishable. The samples of the casting moulds have been processed in the Bonn laboratory in the same way that is applied for pottery characterization for about 30 years. The procedure is described at length in Mommsen et al. 1991. Since 2010 the reactor of the Reactor Institute Delft (Netherlands) is used (described recently in Jung et al. 2015). The Olympia samples have been irradiated there on the 18–10– and on the 15– and 22–11–2013, the Kalapodi samples on the 21–02–2014.

Scanning Electron Microscopy (SEM)

For examination of their microstructure 14 ceramic fragments from Olympia and Kalapodi were examined under a FEI, Quanta Inspect D8334 scanning electron microscope (SEM), coupled with an attached energy–dispersive X–ray spectrometer (SEM–EDS). The fragments were mounted with carbon glue on sample holders exposing fresh breaks of the ceramic body. After a first examination under an optical microscope the fragments were carbon coated. The micro structural examination was focused on the characterization of the ceramic texture and the estimation of the degree of vitrification. One basic question to be solved initially was whether the sampled material was actually related to the casting process and not for example to post–depositional concretions on the metal fragments. The SEM–EDS microanalysis investigated the elemental composition of the ceramic body and possible metal remains providing information about the casting process. For the examination of the ceramic body at least three sufficiently flat areas of typically 200×200 μm^2 up to 500×500 μm^2 were selected on each sample while inclusions or accumulations rich in metal were measured in smaller, adjusted areas.

Fourier Transform Infrared Spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) was employed to complement information obtained by SEM, in terms of the material's composition and thermal history, and to check the samples for possible contaminations with post-depositional concretions. FTIR, which only requires a few milligrams of a sample is particularly suitable for the present case where only exceedingly little material was available for analysis. Representativeness was ensured – as far as possible within the constraints imposed by the nature of the material – by subsampling the powdered sample employed for NAA, rather than by scraping from fragments. IR spectra were measured on pressed KBr pellets. Powdered sample was added to previously dried KBr in the ratio of c. 1:100. Spectra were recorded on a Bruker Equinox 55/S FT–IR Spectrometer in the range of 4000 to 400 cm^{-1} with a spectral resolution of 4 cm^{-1} against air as background, by adding and averaging 30 scans before the Fourier transformation.

ANALYTICAL RESULTS

Contamination According to SEM–EDS

The SEM–EDS analysis of the fragments provided information about possible contamination of the ceramics not only during the casting process but also, in the case of Olympia, during the conservation process of the metal fragments after discovery. These contaminations affect the NAA results and have to be considered during their evaluation. As for the casting process, the examined ceramic fragments presented considerable concentrations of copper and lead (Table 3). This elevated metal content is most likely related to bronzes rich in lead that were used for casting, a small portion of which was absorbed and deposited in the porous ceramic structure (Kearns et al., 2010). Another type of contamination appears in the unexpectedly high zinc concentrations observed exclusively in the ceramic fragments from Olympia with concentrations of up to 20 wt% of ZnO. The use of brass in the Iron Age appears highly unlikely and published analyses of tripod metals indicate absolute zinc concentrations of clearly below 0.2 wt% (Philippakis et al., 1986; Kiderlen et al., forthcoming, with analyses of tripods of group M1 and further references). Even though enrichment of zinc in the ceramic body can be expected due to its comparably high vapour pressure (Kearns et al., 2010), other explanations had to be explored, considering also the absence of zinc in the examined fragments from Kalapodi. The most probable explanation for the zinc enrichment is an electrochemical treatment of archaeological metal objects in order to reduce corrosion products, which reportedly was applied by the excavators of Olympia until the 1960s and was a commonly employed method (Scott, 2002, 354). At Olympia, the technique used was probably the ‘Krefting’s Method’, which involves immersing the metal objects in a sodium hydroxide solution to which zinc granules have been added. During this treatment a small portion of the solution was likely absorbed in the casting ceramics that adhere to the metal fragments. Table 3 demonstrates the correlation of sodium and zinc in the examined ceramic bodies, even though a potential over estimation of the sodium content has to be considered due to the interference of the Na Kα-line with the Zn Lβ-line in the EDS spectrum.

Microstructure and Microanalysis (SEM–EDS)

The rather fine structure of the ceramics without any large inclusions can already be observed under the optical microscope. The colours of the ceramics vary from light brown/buff to dark brown. Furthermore, the microstructures of most of the fragments show a characteristic pore structure with frequent elongated voids or imprints (Figure 3).

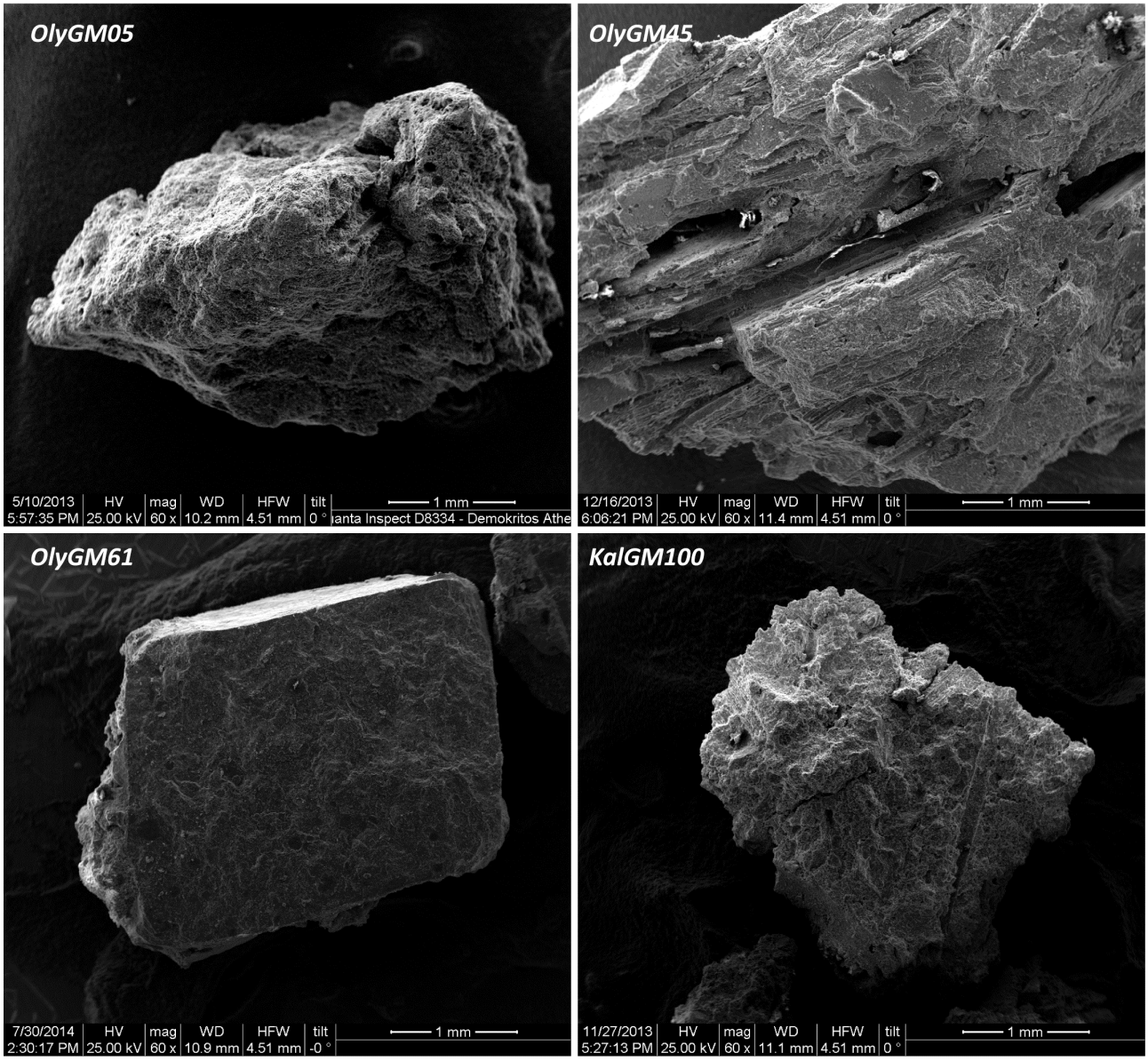

Figure 3: SEM micrographs (secondary electron mode) of fragments of the casting ceramics: Presented are OlyGM 5 (top left), OlyGM 45 (top right), OlyGM 61 (bottom left) and KalGM 100 (bottom right). In most fragments elongated voids or imprints can be observed presumably originating from organic temper that had been burning out during firing of the ceramics or during the casting process.

These presumably originated from organic temper that burned out during the firing of the ceramics or during the casting process due to the heat of the molten metal. Tempering with organic fibres,

either vegetal fibres or animal hair, was a common method in the construction of pyrotechnical ceramics in order to suppress heat transfer and thus thermal shock and to stabilize the unfired ceramic structures (Schneider & Zimmer, 1984; Evely et al., 2012, Hein et al. 2013). The porosity allowed furthermore for the escape of evolved gases (Freestone 1989). Beyond that, the two fragments OlyGM 43 and OlyGM 45 (both from tripods of the "Gratbein"–type and belonging to chemical Group M3) present a clearly layered structure as well (Figure 3). This could indicate that the casting ceramics had been applied onto the wax model in thin layers. On the other hand fragment OlyGM 61 (a chemical loner) appears to be an exception presenting a quite dense structure without visible pores at least concerning the main body (Figure 3). In backscattering mode fragment OlyGM 61 presents bright layers on the surface of this main body corresponding apparently to metallic remains (Figure 4). Another example of obvious metal remains is fragment OlyGM 5 belonging to chemical Group M2 (Figure 4).

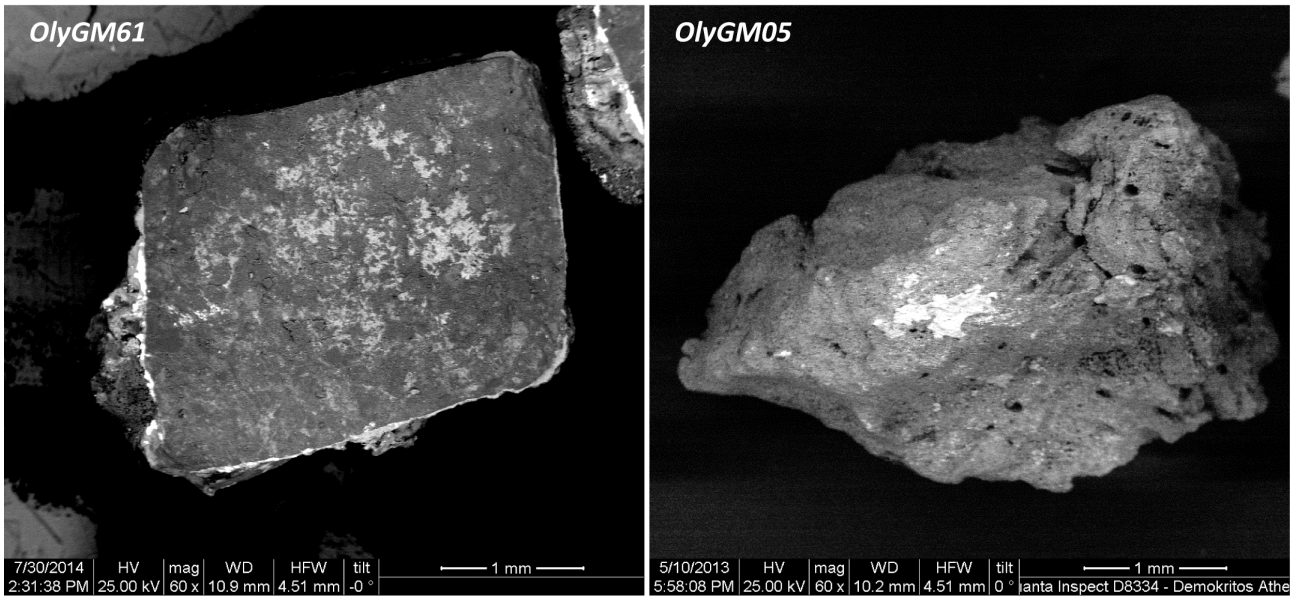

Figure 4: SEM micrographs of fragments of the casting ceramics in backscattering mode: Presented are OlyGM 61 (left) and OlyGM 5 (right). The bright areas correspond to metal remains originating from the casting process.

In larger magnification, the degree of vitrification of the ceramics becomes apparent, which varies among the examined fragments from initial vitrification to extensive vitrification (Figure 5).

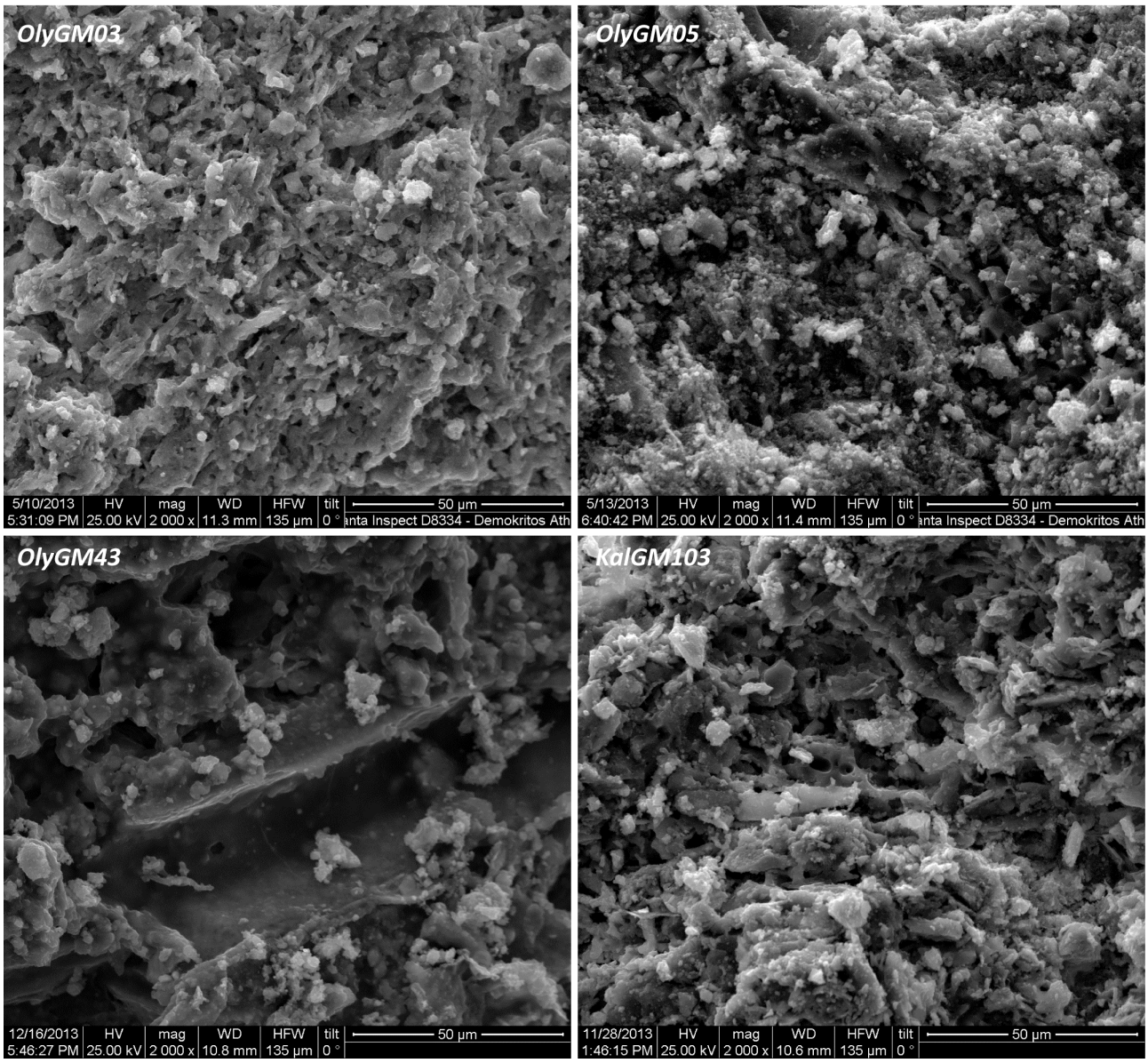

Figure 5: SEM micrographs (secondary electron mode) of fragments of the casting ceramics: Shown are OlyGM 3 (top left), OlyGM 8 (top right), OlyGM 43 (bottom left) and KalGM 103 (bottom right). The microstructure presents the degree of vitrification, which can be set in relation to the temperatures the ceramics were exposed to either during firing or during the casting process.

This corresponds to equivalent firing temperatures of at least c. 800–1000°C (Tite and Maniatis 1975, Hein et al. 2007), coincidentally also confirming that the samples are indeed remains of casting ceramics and not post depositional concretions. These temperatures must have been reached during the actual casting process and not during the initial firing of the ceramics in order to remove the wax model. At least in Classical times, this commonly took place at lower temperatures (Schneider & Zimmer 1984). Inside the pores, vitrification appears to be more advanced supporting

the assumption that the originally present organic material burned out (OlyGM 43 of chemical Group M3, Figure 5).

Apart from the identification of possible contamination, the SEM–EDS analysis provided basic information about the chemical composition of the materials used for constructing the casting ceramics. Even though EDS measurements of irregular surfaces certainly cannot be compared with X–ray fluorescence analysis (XRF) or even NAA in terms of precision and accuracy, the evaluation of measurements in different areas of the same sample nevertheless presented sufficiently low variation allowing the investigation of significant differences between samples. While most of the samples were of homogeneous composition, OlyGM 51 (chemical group M5) appeared to be an incomplete mixture of two different materials. Another exception was fragment OlyGM 61 (chemical loner), the main body of which presented a composition that was clearly different from the surrounding material.

Figure 6 presents a ternary diagram of the SiO_2, Al_2O_3 and the sum of the CaO and MgO concentrations.

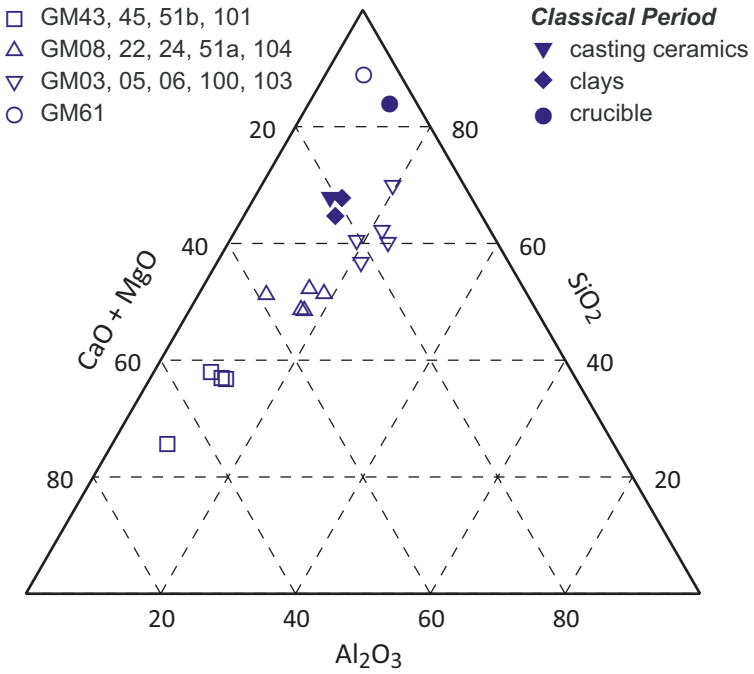

Figure 6: Ternary diagram of SiO_2, Al_2O_3 and the sum of CaO and MgO concentrations in wt.%: Presented are the average compositions of the examined fragments of casting ceramics as measured by SEM–EDS and comparable compositions of material from a Classical bronze casting workshop active in Building A at Olympia which were measured by XRF (Schneider & Zimmer, 1984).

In addition to the average compositions of the examined fragments comparable XRF data of material from a Classic bronze–casting workshop in Olympia are included (Schneider & Zimmer, 1984). Some of the fragments appear to be extremely calcareous, particularly OlyGM 43, OlyGM 45 (both chemical group M3), KalGM 101 (chemical group M6) and a part of fragment OlyGM 51 (M5). Another series of fragments presented a high calcareous composition as well, also exceeding the calcium content of the clays used in the Classical Period (OlyGM 8 [loner], OlyGM 22 [M5], OlyGM 24 [M5], KalGM 104 [M1] and the other part of OlyGM 51). Five of the fragments, however, (OlyGM 3 [M4], OlyGM 5 [M2], OlyGM 6 [M5], KalGM 100 [M1] and KalGM 103core [M4]) presented a similar calcium content as the clays and the casting ceramics from the Classical period, even though the aluminium content appeared higher, which could indicate a comparably higher content of clay minerals. Finally, the composition of the main body of fragment OlyGM 61 resembles ceramics used for the fabrication of crucibles. This, in combination with the evidence presented above, could be an indication that the examined main body of OlyGM 61 is actually an inclusion, e.g. either mudstone or a small piece of grog originating from ground pyrotechnical ceramics.

Finally, some of the metal remains in the ceramic bodies were analysed by SEM–EDS, as their analysis was expected to provide information about the metal used for casting. Table 4 presents some of these measurements. As already demonstrated in the measurements of the ceramic body (Table 3) bronzes rich in lead were used for the casting of the tripods. The correlation in composition between the metal intrusions in the casting ceramics and the metal (alloys) of the respective tripods will be studied in more detail after the pending archaeometrical investigation of metal samples. The absolute zinc content in the examined metal remains appears to be smaller than in the ceramics, which supports the assumption about the conservation treatment as source for the zinc in the ceramic matrix.

Exposure to Heat of the Casting Ceramics (FTIR)

As the FTIR results correlate to a large extent with the below discussed NAA classification, they are discussed in relation to the NAA groups. Samples of the NAA group M1 for instance present an intermediate calcium content. The absence of CO_3 bands in many of these samples, together with absorption bands likely indicative for high temperature silicates, in particular diopside (see Figure 7

a) with distinct bands, i.e. main Si-O str band at frequencies of 1060-1070 cm^{-1}, alongside with shoulders at c. 982, 920, 877, 672, 510 cm^{-1} (Omori, 1971) indicates relatively high equivalent firing temperatures. This is observed both for casting moulds and the core analysed. Diopside is formed in calcareous clay as a high temperature phase, typically after firing to c. 900°C and above (Maggetti, 1982). Bands characteristic for calcite in OlyGM 26, OlyGM 54, KalGM 104 indicate somewhat lower firing temperatures for the particular samples, but at least in sample KalGM 104 the relatively high frequency of the main CO_3 band at 1443 cm^{-1} probably indicates recrystallized calcite (Shoval, 2003). Also the two samples of NAA group M2, both from the same tripod, show absorption bands indicative for diopside, and have likely been exposed to relatively high equivalent firing temperature.

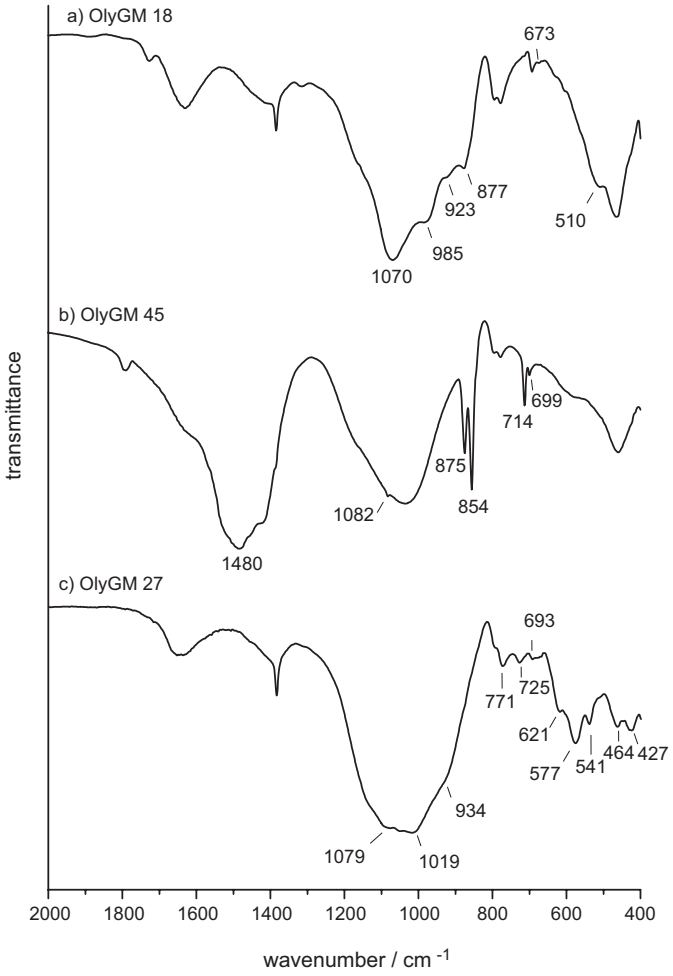

Figure 7: FTIR spectra of samples from casting cores and residues of moulds adhering to tripods. Typical bands of components identified, as discussed in the text, are indicated. (A sharp peak observed at 1385cm^{-1}, which is observed in all spectra and may be caused by a nitrate species, is likely due to contamination).

Spectra of samples of NAA group M3 clearly differ from other spectra. They all exhibit a strong CO_3 band at 1429-1434 cm^{-1}, alongside associated bands at 875 and 714 cm^{-1}. In OlyGM 9 and OlyGM 45 the main CO_3 band is found at higher frequencies (1476-1485 cm^{-1}). This – alongside shoulders at 1082 cm^{-1} and another associated band at 857 cm^{-1} – indicates the presence of a second calcium carbonate polymorph, aragonite (Russel, 1987) (see Figure 7 b). Aragonite can also be detected in OlyGm55. In these samples, aragonite and probably also calcite are likely neo-formed rather than part of the original clay paste. Calcium carbonates are converted by heat during the firing process to CaO, which will react with the clay to form calcium alumina silicates upon further heating. Unreacted CaO will recrystallize over time, typically forming the thermodynamically stable polymorph calcite. Experimental studies indicate that the neo-formed calcium aluminium silicate gehlenite may break down to metastable aragonite under humid burial conditions and in the presence of humic acids (Heimann and Maggetti, 1981). Aragonite, however, has also been observed to have formed on the outside surface of technical ceramics used for bronze casting in the Roman period (Eliyahu–Behar et al, 2009). Since aragonite crystallisation is favoured in the presence of even very low concentrations of larger sized cations such as Pb^{2+}(Wray & Daniels, 1957), it must be assumed that impurities from the bronze are the reason for the localised crystallisation of aragonite over calcite on the metal–cast interface in highly calcareous linings. Exposure of samples to heat is indicated also by a shift of the main Si-O stretching band in many samples (found at 1031-1045cm^{-1}, with the exception of OlyGM 43, where it is found at 1020cm^{-1}) and the observation of a combined Al-O and Si-O deformation mode at 468-461 cm^{-1}.

Samples of NAA group M4 showed some variability with apparent lower fired samples alongside higher fired specimens. Moreover, three of the samples from the M4 group analysed by FTIR (all of them from casting cores: OlyGM 27core, OlyGM 38core, KalGM 103core) are dominated by a feldspar spectrum, possibly anorthite, as indicated by the pattern of absorption bands between 800 and 400 cm^{-1}. However, a band at 427 cm^{-1} could indicate that other feldspar species might also be present (Russel, 1987). Feldspars are a relatively common aplastic component of many clay pastes, but anorthite can also be formed as a high temperature phase when heating ceramic pastes (Cultrone et al., 2001). Generally there appears to be a relatively high variability in terms of heat exposure between samples of NAA group M5, indicated by the relative shift of the main Si-O str. band. For the mould remains adhering to tripod DN 116, from which two samples have been analysed, OlyGM 22 appears to have been exposed to less heat than OlyGM 64. Unlike in M4 samples, the spectrum of the only M5 core sample analysed, KalGM 102, does not differ significantly from other spectra, and there is no indication for particularly high heat exposure.

KalGM 101 (NAA group M6) is the only sample analysed which shows a broad, not well defined absorption band around 3620 cm^{-1}, indicative of clay–bound hydroxyls. It is unclear whether these are original hydroxyls of a poorly defined clay mineral or if they indicate a rehydroxylated species. Both the SEM and macroscopic evidence, however, indicate some exposure to heat. The apparently relatively low heat exposure may be due to the fact that the particular sample was taken from the outer surface of a relatively thick remain of the mould, in some distance (ca. 10 mm) from the heat source during the casting process.

In summary, for samples, for which the main Si-O stretching band is shifted to higher wavenumbers, a relatively high equivalent firing temperatures can be assumed, similarly as for samples, for which FTIR attests the presence of high temperature phases. Bands characteristic of clay–bound hydroxyls were not found in the samples analysed (with the exception of KalGM 101), which, alongside the collapsed Al-O and Si-O deformation bands in these samples, indicates that casting ceramics had been exposed to temperatures exceeding dehydroxylation temperatures of clay minerals. This result confirms that samples are not contaminated with postdepositional concretions. In general, there is an apparent tendency of samples assigned to the below discussed NAA groups M2 and M1 to high equivalent firing temperatures. High temperatures are also assumed for some samples of NAA group M4, in particular for the core samples analysed of this group. Somewhat higher variation is observed in NAA group M5, in which there is also no indication for particularly high temperatures for the core sample. On the other hand it would appear that M3 samples have been exposed to somewhat lower equivalent temperatures. This group is also clearly different compositionally, which apart from the potentially different provenance is likely related also to technological reasons.

Variation of the Exposure to Heat Observed by SEM and FTIR

Overall, samples appeared to have been exposed between intermediate and high equivalent temperatures.

The variation in heat exposure within samples derived from the same tripod might quite easily be explained by a sampling bias introduced by minimal sampling of an inhomogeneous material: even if casting ceramics had been exposed to low–intermediate temperatures during the preparation of the moulds, subsequent casting exposed the material closest to the liquid metal to high temperatures. The restricted thermal conductivity of the clayey material, however, further enhanced by porosity introduced by burned-out organic temper (Hein and Kilikoglou, 2007, Hein et al. 2013),

resulted in a temperature gradient within the ceramic body. Accordingly, it is expected that casting moulds will show a differential firing and microstructural as well as compositional (in terms of mineralogy) profile through a cross–section. In addition, cores will perhaps generally have reached higher temperatures than the corresponding moulds, since the cores were entirely surrounded by the metal. Subtle differences in relative distance of sampled mould or core material from the metal body will thus likely affect analytical results. Finally, also a variation of the temperature of the liquid metal might be considered, which was cooling down inside the mould depending on the distance from the inlet.

More difficult to explain is variation in heat exposure between different compositional groups established by NAA. It can be noted though that the comparably low equivalent temperatures observed in M3 may be related to the fact that according to published data tripods of the Gratbein type normally were cast of tin bronzes, which had a melting point considerably lower than the alloys normally used for the other tripod types. These technological constraints certainly have to be further investigated during the course of the running project (Kiderlen et al. forthcoming).

Statistical Data Evaluation of NAA Results and Special Group Forming Procedure

In order to find samples of similar composition, statistical group forming procedures are generally in use. In Bonn, a special filter method has been developed calculating a modified Mahalanobis distance in the multidimensional concentration space considering a) the experimental measurement uncertainties and b) a possible variation of all concentration values due to a constant factor often called dilution factor (Mommsen et al., 1988; Beier & Mommsen, 1994ab, Mommsen et al., 2002). Whereas b) can be taken into account by other statistical group forming procedures if concentration ratios are used, a) cannot be considered by the often used Principal Component Analyses (PCA) or common Cluster Analyses (CA) producing dendrograms.

The result of a first attempt using the statistical Bonn filter method in the usual parameter settings for the grouping of pottery was that the material of the casting ceramics varied strongly in composition. No sample was found to be similar to another one; all were flagged to be chemical singles with large distances to all other samples. Assuming that not all the moulds of the tripods found at Olympia have been made with different pastes, the varying concentration values of elements in different samples have been inspected. There are two reasons for the occurrence of unexpected different compositions: Some elements might have been contaminated in different ways and show varying concentrations due to the contact of the mould material with the hot liquid metal. Or/and the concentration values of some elements might have been wrongly determined, since

casting moulds cannot be treated like normal pottery samples during standardized spectrum evaluation. Such differently contaminated or wrongly determined elements cannot be taken into account if groups of samples of similar composition have to be formed.

The raw data of all the samples from casting cores and from residues of moulds adhering to tripods, as well as of the comparative material are given in Supplementary Table 2. Elements with an unusually high concentration or with an unusually high variation in the sample set of the moulds that are determined in our usual spectrum evaluation procedure are As, Cu, Sb, and Zn. The metal As is known to be not stable in pottery as well, since it evaporates depending on the firing temperature. The high Cu concentrations are not surprising in moulds of bronze objects and they might also be due to Cu-particles scraped from the tripod leg by the drill bit during the sampling procedure. A different reason for the high values of Sb (often admixed in Pb that cannot be measured by NAA) other than a contamination during the casting is not known to us. The possible contamination of Zn by the restoration procedure of the tripods from Olympia was expected as mentioned above and is now proven since the mould samples from Kalapodi, that have not been restored with this method, do not show the high Zn contamination. As seen in the spectra, other additional metal elements normally not present in pottery above our detection limits occur as contamination in the mould samples. These are Sn and Ag. The absolute concentrations cannot be stated since the content of both elements is not determined in the Bonn pottery standard and a special standard has not been added during the irradiations.

Special care and notice was taken during the spectrum evaluation to determine correct concentration values. The unusually high concentrations of the metals mentioned above might result in unusually high line intensities overlapping with lines normally free of interference. The strong Sn and Ag lines in the spectra have been checked not to interfere with a line normally evaluated. But an example of a necessary correction is the Cs-134 line at 604.66 keV that is disturbed by a Sb-124 line at 602.58 keV, if Sb is in the range of a few ppm or higher. At Sb concentrations below 1 ppm, as normal in pottery, this interference is weak and can be neglected. A second Cs-134 line at 795.76 keV is free of interference. This line is taken here and serves normally as redundant value for Cs. Another interference concerns the radiation from Sc-46. A strong line of Zn-65 at 1115.52 keV will disturb the Sc-46 line at 1120.52 keV. But also for Sc there exists a second undisturbed line at 889.25 keV used for reliable Sc concentration values here.

After stepwise omitting the elements considered to be contaminations as well as elements with an unusually high scatter of concentrations, the filter method was finally applied again using the

reduced set of only 14 elements (Ce, Eu, Fe, Hf, La, Lu, Nd, Sc, Sm, Ta, Tb, Th, U, and Yb) in search of groups of similar composition and for the best relative fit factor calculation. The final element choice contains all the Rare Earth Elements (REE) measured in Bonn. It can be concluded that the casting process has not influenced their concentrations in the moulds considerably. Fe is found to be a reliable value for grouping, since the high concentrations of a few percent in the moulds is not sensitive for a possible contamination of much lower concentration. Although the use of a tungsten carbide (WC) drill is known to contaminate the samples not only with W, but also with Co and Ta, the low scatter of Ta in the different groups shows that the contamination by the drill material is negligible here. The rather soft remains of the casting cores and the moulds adhering to the tripods did not abrade the much harder drill material.

The result of the grouping procedure using 14 elements only was the formation of 6 groups for the samples from tripods found at Olympia and Kalapodi and for the comparative technical ceramics found at these sites (M1 / M2 / M3 / M4 / M5 / M6), with a 7th group consisting only of comparative technical ceramics found at Olympia (M7). The average concentration values of the groups are given in Table 5 showing 32 elements. They have been obtained with a set of best relative fit factors calculated with the reduced set of 14 elements given above. They are flagged with a * in Table 5. But during the group forming procedure for pottery samples, a larger set of 25 elements is normally used (given in Table 5). In order to compare the new groups with the reference groups in our database of groups that have been calculated with the full set of elements, a test with this full set was done. The increased number of elements will influence only the determination of the best relative fit factors, and this increase resulted in about the same set of factors and thus did not largely change the average grouping values. The reason is that the calculation of these factors takes the scatter of the elemental concentrations expressed as root mean square deviations or spreads σ into account and elements with large scatter have only little weight during these calculations. The same is true for the calculation of the modified Mahalanobis distances of the group members and also non–members. These distances of single samples are given in units of the average spread values of the given group in direction to the sample point to be tested in concentration space. As can be seen in Table 5, the added 11 elements all have large spread values. Therefore, if the elemental number is increased from 14 to 25, the assignment to a group or the exclusion from a group did not change for the individual samples. But during the group forming procedure, where the final groups and their spreads are still unknown, the temporary reduction of the elemental number was needed and helpful.

The individual sets of the raw concentration values are listed in Supplementary Table 2. They have to be multiplied by the best relative fit factors with respect to the average concentrations of their group. The list of group members and the best relative fit factors applied are shown in Table 1.

Archaeometric Discussion of NAA Groups

The 7 groups show clearly unusually high concentrations of Cu and Zn presumably due to contamination, but also Sb is e.g. unusually high for clays and therefore probably a contamination during the casting process originating from the copper alloy. In fact, contents of sometimes up to 1.78% Sb have been published for tripod metals (Philippakis et al., 1986, sample no. 120).

The 3 groups M1, M4, and M5 are not very different in composition. Group M3 has quite similar concentration values to this triple as well, if the high Ca content of about 20 % is not considered and if all values are raised by about a factor of 1.9. Since groups M4 and M5 contain comparative material from Olympia and the group of comparative technical material from Olympia M7 is also close in composition, we assign all these five groups to workshops in Olympia itself or in its vicinity.

With higher Sc, Cr and Ni and lower Ce and La values (see Table 5) the 3 tripods of group M2 have a composition that is distinctly displaced in concentration space from the other groups.

Group M6, consisting of one tripod found at Kalapodi and all of the comparative material sampled from this site, is quite homogenous and clearly different from the groups connected with Olympia.

Figure 8 depicts the result of a discriminant analysis for the 7 groups demonstrating their differences in composition clearly.

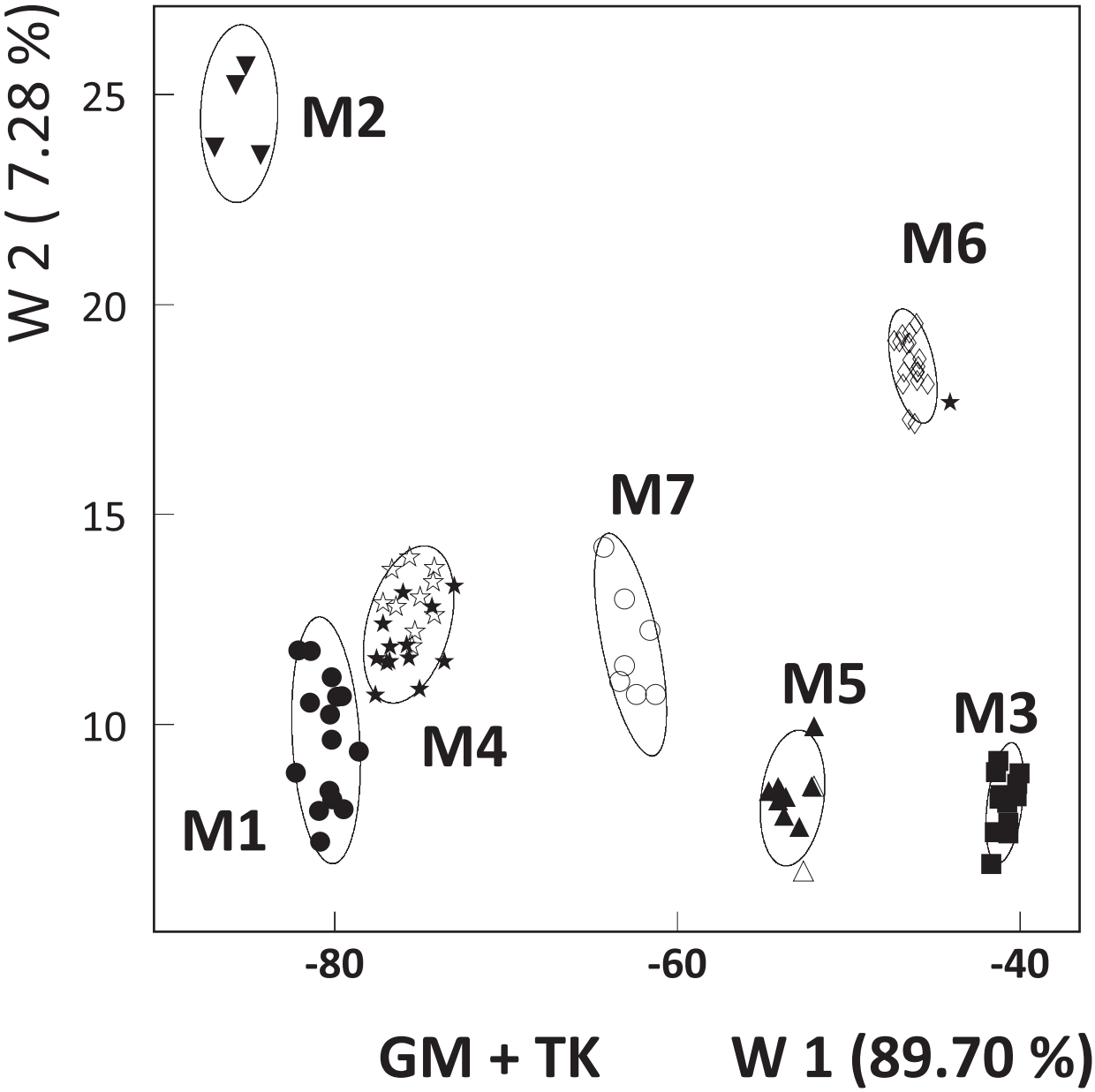

Figure 8: Result of a discriminant analysis of the grouped samples, assuming 7 clusters. Closed symbols: Clay cores and mould residues adhering to tripod fragments excavated at Olympia and Kalapodi. Open symbols: Fragments of pyrotechnical ceramics from workshop debris excavated at the same sites. Individual data have been corrected for dilution. Plotted are the discriminant functions W1 and W2, which cover 89.7 % and 7.3 % of the between–group variance. The ellipses drawn are the 2σ boundaries of the groups explained in the text.

The main concentration differences between the groups assigned to the region of Olympia, if they are normalized with the average spread values, are:

– Fe and Sc are lower and Hf and Ce higher in M1 compared to M4. All other elements statistically agree considering the spread value normalization. The bar diagram Figure 9 shows these normalized differences (distances) of the concentrations of the groups M4 – M1 for 32 elements.

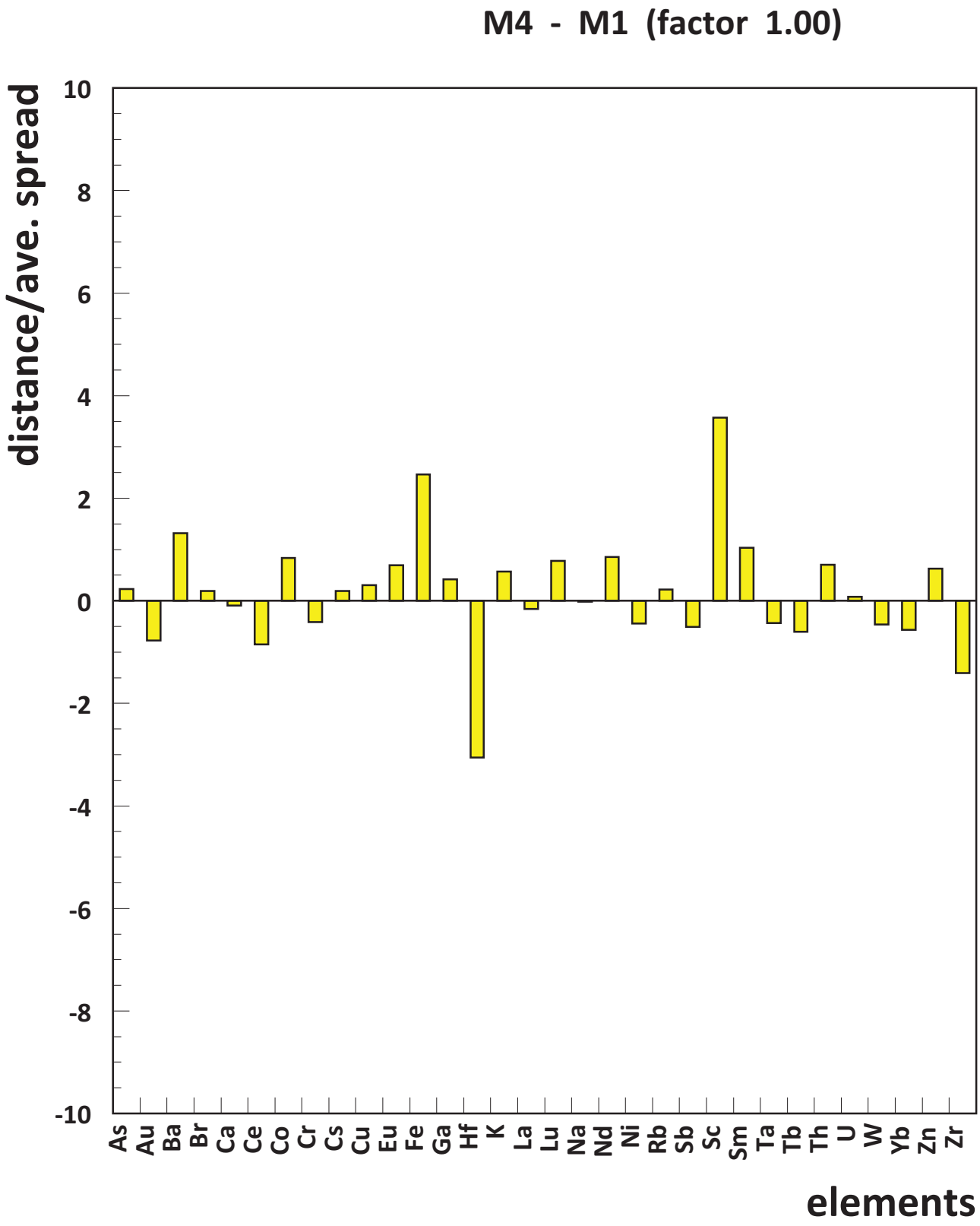

Figure 9: Graphical comparison of chemical compositions of group M1 and group M4. Plotted are the differences of the concentration values normalized by the average standard deviations (spreads). There is not much difference in composition of the two groups except for Fe and Sc that are higher in M4 and Hf that is higher in M1.

– M3 has an unusual high Ca value of nearly 20 %.

– M3 and M5 generally have lower concentration values compared to M4 and M1. The average best relative fit factors using the 14 elements given above with respect to M4 is for M3 1.91 and for M5 1.57. If M3 is multiplied with this large fit factor, it statistically matches M4 with a – considering the spread values – only slightly increased Cr value. For the factor–adjusted pattern M5 the concordance with M4 is also convincing with larger deviations for Hf and Cr only.

M7, the 6th group from Olympia and containing no tripods but only comparative technical material also has lower concentrations compared to M4. However, a similarity to this group is given again, if a best relative fit factor of 1.33 is applied. As for M5, Hf and Cr are enriched and additionally La is depleted.

An unexpected result was that the compositions of 4 samples from tripods excavated at the sanctuary of Kalapodi matched for the 14 elements chosen the compositions of the casting ceramics from Olympia. Patterns M1 (KalGM 100 and 104), M4 (KalGM 103) and also M5 (KalGM 102) occur in Kalapodi. A match of 14 elements only should not be considered an absolute evidence for provenance (Harbottle 1991), but it is enough to establish the working hypothesis that the relevant 4 tripods have been made in a workshop in Olympia and brought from there to Kalapodi in ancient Phocis.

Comparison of NAA Groups with Reference Pieces: Provenance

Although the 6 elemental concentration patterns of clay cores and casting moulds of tripods have unusually large spreads for several elements that give the groups a large extension in concentration space for these elemental coordinates, they do not overlap with other groups of known provenance stored in our database. Reference material of known origin is therefore needed to determine the production sites of the casting cores and moulds. Since the technical material from Olympia definitely stems from casting workshops at this site, and since several samples of this material match 2 groups of the moulds, these groups and with them also the other groups with not very different concentrations (exceptions are M2 and M6) can be assigned to the area of Olympia. The known pottery groups ACb2 (Zuckerman et al., 2010) and OlyA (Mommsen et al., in press)

assigned to a production area somewhere in Elis/Achaia do not statistically match any of the mould groups assigned to Olympia (M1, M3, M4, M5), but are generally close in concentration space with the largest deviation of higher Sc values.

A few individual samples of the pottery groups from Elis/Achaia, located in concentration space at the peripheral zone of their groups in direction to mould groups assigned to Olympia, have a certain probability to belong to these mould groups. Clay samples from Cape Katakolo (Olym T2, T2rep: 37°38’37’’N, 21°19’06’’O, best relative fit factors 1.03 and 1.01, respectively) and also from a construction pit in the centre of the town Salmoni (Olym T4: 37°39’37’’N, 21°31’58’’O, factor 1.08) are both members of group OlyA and statistically match also group M4 except for their slightly enhanced Sc values. Another clay sample from the slope about 30 metres NE of the Olympia excavation house (Olym T3: 37° 38’ 35” N, 21° 37’ 52” O, factor 1.04) matches in composition M5.

We do not know the pattern of M2. With only 4 samples it is not yet very well defined, but with high Cr and Cs values it is different from the local mould groups. According to its position in the multidimensional concentration space it has some resemblance to groups assigned to Attica.

M6 can convincingly be located at the sanctuary of Kalapodi because it contains 18 samples of comparative material from this site.

ARCHAEOLOGICAL DISCUSSION

Correlation between Multiple Samples and Chemical Groups

Normally, the samples were taken from the innermost area of a casting mould, rarely more than some millimetres away from the surface of the resulting bronze–artefact. This inner area of a mould sometimes consists of layers of very thin strata, as demonstrated above, which potentially might or might not differ from each other in coarseness and/or chemical composition. Nevertheless, as visualized in Table 1 multiple samples from a given tripod, e.g. from different legs, tend to fall in one and the same chemical group. This means that chemical variation within the paste(s) prepared for the inner areas of the different moulds made for the legs of a given tripod was normally lower

than the variances of our respective chemical group. On the other hand, a paste prepared for a casting core may belong to another chemical group than the paste prepared for the inner layer of the mould of the same given tripod (DN 100 and DN 110 in Table 1). This may indicate that the resolution of the group forming procedure is well adapted to the practical peculiarities of the procedures used in ancient casting workshops and is neither too high nor too low.

Tripod Production at Olympia

Four chemical groups are connected with artisans casting tripods at Olympia:

– M5 is confirmed since chronological phase 4 (ca. 925 – 850 BC) for a total of 5 tripods from Olympia and 1 from Kalapodi and is still used much later for 5th century BC moulds (Table 1 and 2). This long time span may indicate that M5 is not a paste consisting of a complex mixture, but a natural clay which was only minimally processed. This hypothesis is corroborated by the geological sample T3 taken from the marly clay at the hill just outside of the fence of the modern excavation house that is fitting M5 nicely.

– M4 is also established since chronological phase 4 (ca. 925 – 850 BC) and accounts for a total of 11 tripods found at Olympia and Kalapodi, but also contains many 5th century and later moulds from workshop debris excavated at Olympia (OlyTK 1, (8?), 9, (10?), 13, 14, 15) as well as debris of potter's or tile maker's kilns excavated at the same site (OlyTK 18, 20) (Table 1 and 2). Again, the long period of use and the general argument that for the simple purpose of constructing a kiln, difficult clay preparation techniques would have been used rarely, corroborates the hypothesis that also paste M4 is not a complex mixture of different clays and/or other admixtures, but instead one single naturally occurring clay used with little processing. This is supported by the fact that M4 is close in composition to the geological samples T2 (from Katakolo) and T4 (from Salmoni, a site half way between Olympia and Katakolo).

– Tripods assigned to M3 are typologically highly homogenous and belong exclusively to the well–defined group of the ‘Gratbein’–tripods of phase 7 (ca. 750 – 700 BC). This paste is similar to paste M4, except that the concentrations on the average are only 50 % of those of M4 indicating a strong dilution including one by Ca (an average of about 20 %).

– M1 is found since typological phase 3 (ca. 975 – 925 BC) for 15 tripods excavated at Olympia and Kalapodi, but it is not found in the comparative material. The workshops processing paste M1, however, are certainly also situated close to Olympia, since in two cases (tripods DN 100 and DN 110) this paste was used for the core of a leg whose mould was made of paste M4 (Table 1). If the paste with this pattern really was no longer used by the 5th century, as it seems at the moment, it cannot be decided with the limited number of samples from this period.

There are several possible explanations why so many different chemical groups show up within the clay pastes used at Olympia for the manufacture of moulds for tripods. Presumably, we are dealing with manifold combinations of intentional choice, negligence, and peculiarities of local geology and clay beds. At this point we have to remind the reader that our chemical classification relies on trace elements and not on the main components and the additives. Our classification therefore does not have direct correlation with technical properties and performance.

Chronologically, M1 is the first paste we have evidence of to be used in Olympia (since phase 3). Only considerably later, in phase 4, M4 and M5 appear (Table 1). However, since our samples do not cover the chronological phases 1 and 2, and because phase 3 is also only sparsely represented, an argumentum ex silentio is not possible and any of these three pastes actually may have been used much earlier as it seems.

Also, there is no statistical basis to sort out whether the artisans active at Olympia in phases 3 and 4 used the three pastes defined by us as M1 / M4 / M5 interchangeably, or if they had certain preferences related to technology, workshop tradition, accessibility of certain clay beds, or workability.

Later, in the chronological phases 5 and 6, the three pastes M1 / M4 / M5 definitely were used not only at the same time, but also by the same persons. This is evident for the artisans who cast the tripods DN 100 and DN 110 and used two different pastes for the cores and the moulds, but also for the typologically well–defined group of "Matrizenbein"–tripods in general (underlined in Table 1). To say more, parallel use is not only attested in terms of workshop and person, but also in terms of technical function, since all three chemical groups in question were used both for cores and for moulds. Therefore, in the perspective of the artisans active at Olympia during phases 5 and 6, the three pastes in question seem to have been interchangeable at least up to a certain point. This attitude is somehow analogous to the evidence from the debris of the much later sculpture–founders of the 5th century BC active in the area of the so–called Building A, who seem to have used M5 and M4 as well as M7 interchangeably for the first layer of their moulds (Table 2).

The practice of the artisans responsible of the "Gratbein"– tripods (bold in Table 1), however, was different. They continuously used paste M3 which is a very diluted version of M4. This choice may have been part of a technological strategy, since the "Gratbein" – workshop evidently set its pride in achieving larger formats than ever seen before and succeeded to cast legs measuring up to ca. 1,7 m and weighting about 30 kg (DN 176) since its rise in early phase 7.

Concentration of Workshops at Central Places

Because the chemical patterns of groups M1 / M4 / M5 and M3 may represent pastes made from geographically dispersed clay deposits, the question may be raised if a localisation can be pinpointed to the immediate area of the sanctuary of Olympia or if we should consider a wider region of activity, e.g. artisans travelling between different villages within Elis. The first version is more likely because workshop debris from artisans casting a "Matrizenbein"–tripod were excavated within the sanctuary (Phase 6; Maaß, 1978, 26 Inv. T 859, Beilage 11), as well as workshop debris from casting a statuette for a "hammered" tripod or a "Gratbein" –tripod (Phase 7; Moustaka and Born, 1982). In addition to Olympia, workshop debris from the casting of tripods is known only from the sanctuary at Akovitika, which was an important regional centre in the Messenian Pamisos valley (Phase 4 or 5; Kiderlen & Themelis, 2010, 26–31; 127–129 cat. M1 with references), and from the rich settlement at Lefkandi on Euboea (Phase 4; see above and Mazarakis Ainian, 2012, 133). A reason for this distribution could be that these competent artisans went (and were summoned) to places where they could expect to meet persons rich enough to potentially become contractors. Certain sanctuaries, as is shown by the dedications of their visitors (Figure 2), were at least seasonally visited by a much larger number of potential contractors than any rich settlement. If the few able craftsmen were known to stay during a season or for a longer time at a certain sanctuary, this would offer ample opportunities for potential contractors to get into contact with them.

Political Links between Olympia and Kalapodi

Only one of the 5 analyzed tripods found at Kalapodi belongs to M6, the local paste of Kalapodi, which contains all the 18 samples of comparative technical material from this site and which is not in any way similar to the patterns from Olympia. Four belong to M1, M4 or M5 (Table 1). This implies that a large percentage of the tripods dedicated in Kalapodi were made at Olympia, which is very astonishing. It quite surely reflects travel routes of the respective contractors (= donators) and sheds light on their movements within a network of contemporaneous political meeting points such as the discussed sanctuaries. Travel routes of donators are also indicated by our finding that tripods were likely brought from somewhere else (Attica?, Boeotia?) to Olympia as early as phase 4 ca. 925 – 850, as indicated by the chemical composition of their respective casting mould residues (M2). In order to visualize extant archaeometrical information on the relative importance of production sites and on the movement of tripods and donators, in Table 6 we list provenances, find spots and chronological phases.

Mobile Workshops

In terms of typology and artistic style, the tripods of chemical group M2 are not distinguishable from the assemblage of those made at the same time at Olympia. In phase 5, tripod DN 10163 made at Kalapodi is very similar to tripod DN 99 made at Olympia. This suggests that artisans travelled from one centre to the other.

Further Research Perspectives

Provenance–data and consequent conclusions on the movements of objects, contractors, and artisans suggest a thriving supra–regional network of sites where expertise (artisans) and demand (contractors) met. This network comprised sanctuaries and settlements and was a dynamic system. Although only a small part of this network was studied so far, it seems evident that both contractors and artisans had access to more than one site and could choose where to go. Changes in relative importance of production sites as well as in the patterns of movements of both contractors and artisans therefore should be indicative for important political and economic phenomena. In order to further process provenance data from tripods, we plan to connect them systematically with data on

the trade of raw materials (copper; Kiderlen et al., in preparation) and with an analysis of find spot distribution.

CONCLUSIONS

According to this pilot study, NAA allows a good internal grouping of the chemical trace element composition of ceramic pastes that were used for casting moulds and casting cores in EIA and Classical Greece. If comparative material from workshop debris is provided, these internal groups can be localized.

In the case of EIA tripod cauldrons and comparative material found at Olympia and Kalapodi, we established seven chemical groups (M1-M7). Five groups are connected with Olympia, one with Kalapodi, and one is not localized yet.

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TABLES

Table 1: Samples from tripods (top) and comparative material (bottom) analysed with NAA. The table is arranged according to chemical groups and with indication of the chronological phases of the tripods.

DN is the internal ID-number of the tripods. OlyGM = sample from a tripod excavated at Olympia; KalGM = find spot Kalapodi. Samples marked "core" are from casting cores, all others from mould-residues. Tripods of "Matrizenbein"-type are underlined (e.g. DN 116); tripods of "Gratbein"-type are printed bold (e.g. **DN 176**).

Suites of multiple samples from a given tripod are *printed in italics*. Suites extending over different chemical groups are indicated with *. Best relative fit factors with respect to the grouping values (see Table 4) are given in brackets. Analysis with FTIR is indicated with §.

NAA group / chronological phase	M1	M4	M5
3 (ca. 975-925 BC)	DN 772: OlyGM 54 (1.16) § DN 1163: OlyGM 58 (1.13) DN 10158: KalGM 100 (1.07) §		
4 (ca. 925-850 BC)		DN 49: OlyGM 34 (1.02)	DN 779: OlyGM 6 (0.63) §
5 (ca. 850-800 BC)	DN 84: OlyGM 14core (0.93) § DN 87: OlyGM 57 (0.91) § DN 93: OlyGM 30 (0.89) DN 95: OlyGM 32 (0.91) *DN 100*: OlyGM 48 (1.02)* DN 747: OlyGM 20 (0.84) §	DN 72: OlyGM 3 (1.13) § DN 82: OlyGM 1core (0.77) DN 99: OlyGM 46core (1.34) *DN 100*: OlyGM 38core (0.82)* § *DN 788: OlyGM 41 (0,70), 66 (0.80)* DN 10167: KalGM 103core (0.83) §	DN 5: OlGM 51 (1.87) § DN 10166: KalGM 102core (1.33) § DN 97: OlyGM 24 (0.78) §
6 (ca. 800-750 BC)	DN 104: OlyGM 42 (0.94) § *DN 110*: OlyGM 26 (0.93)* § DN 117: OlyGM 10 (1.15) § DN 123: OlyGM 18 (0.96) § DN 1156: OlyGM 53 (0.92) § DN 10169: KalGM 104 (1.42) §	*DN 110*: OlyGM 27core (0.77)* § DN 111: OlyGM 17 (1.04) § *DN 113: OlyGM 25 (0.95), 62 (1.02)* § DN 793: OlyGM 49 (1.10) §	*DN 116: OlyGM 22 (0.82) §, 63 (0.80), 64 (0.79) §, 65 (1.38)* DN 119: OlyGM 37 (1.29)
7 (ca. 750-700 BC)			
totals	15 samples (1 from core) from 15 tripods	13 samples (5 from core) from 11 tripods	9 samples (1 from core) from 6 tripods
comparative material		OlyTK 1 (1.20), 8 (1.17), 9 (1.25), 10 (1.14), 13 (1.25), 14 (1.11), 15 (1.20),18 (0.92), 20 (1.00), 20re (1.06)	OlyTK 11 (0.87), 17 (1.07),

NAA group / chronological phase	M3	M2	M7	M6	chemical loners
3 (ca. 975-925 BC)					DN 12: OlyGM 29
4 (ca. 925-850 BC)		DN 73: OlyGM 5 (1.03) DN 781: OlyGM 39 (0.91) *DN 783: OlyGM 4 (0.96)* §, *52 (1.11)* §			DN 47: OlyGM 33 DN 740: OlyGM 61 §
5 (ca. 850-800 BC)				DN 10163: KalGM 101 (1,99) §	DN 91: OlyGM 59 DN 128: OlyGM 19 DN 1131: OlyGM 36 §
6 (ca. 800-750 BC)					DN 108: OlyGM 40 § DN 114: OlyGM 16
7 (ca. 750-700 BC)	***DN 176****: *OlyGM 9 (0.95)* §, *13 (1.07), 35 (1.04)* § ***DN 180****: OlyGM 43 (0.95)* §, *56 (0.95)* § ***DN 181****: OlyGM 11 (1.12)* §, *15 (0.65)* §, *47 (0.96)* §, *55 (1.29)* § **DN 182**: OlyGM 45 (1.11) § **DN 185**: OlyGM 44 (1.21) **DN 187**: OlyGM 2 (0.95) §				***DN 176****: *OlyGM 21* **DN 178**: OlyGM 8 § **DN 179**: OlyGM 12 **DN 183**: OlyGM 23 §
totals	12 samples from 6 tripods	4 samples from 3 tripods	no samples from tripods	1 sample from a tripod	12 samples from 12 tripods
comparative material			OlyTK 2 (1.03), 3 (1.02), 4 (1.01), 5 (0.96), 6 (0.99), 7 (0.97), 16 (1.02)	KalTK 1 (0.96), 2 (1.03), 3 (0.96), 4 (1.05), 5 (0.94), 6 (1.02), 7 (0.94), 8 (1.09) 9 (1.26), 10 (1.01), 11 (1.03), 12 (0.94), 13 (1.02), 14 (0.99), 15 (1.00), 16 (0.94), 17 (0.99), 18 (1.01)	OlyTK 12, 19

Table 2: Samples from comparative material found at Olympia (mould-fragments from large-scale bronze casting and other technical ceramic) listed according to context and possible function. Membership to chemical groups is indicated together with the respective best relative fit factors in brackets.

area / context	**sample**	**mould-fragments from large-scale bronze casting, mostly sculptural**	**possibly metallurgical**	**walling / socle of tiler's or potter's kiln?**
foundry in Building A (ca. 440/30 BC)	OlyTK 13	M4 (1.25)		
	OlyTK 14	M4 (1.11)		
	OlyTK 16	M7 (1.02)		
	OlyTK 17	M5 (1.07)		
workshop debris ("Formenschicht") near to Building A (ca. 440/30?, deposited ca. 390/385 BC)	OlyTK 10		M4 (1.14)	
	OlyTK 11		M5 (0.87)	
	OlyTK 12		chemical loner	
workshop debris ("Formenschicht") near to Building A? (ca. 440/30?; deposited ca. 390/385 BC?)	OlyTK 15	M4 (1.20)		
Echo Stoa (deposited ca. 460/55 BC?)	OlyTK 1	M4 (1.20)		
	OlyTK 2	M7 (1.03)		
	OlyTK 3	M7 (1.02)		
Stadion, phase III A (deposited ca. 460/55 BC)	OlyTK 4	M7 (1.01)		
	OlyTK 5	M7 (0.96)		
	OlyTK 6	M7 (0.99)		
	OlyTK 7	M7 (0.97)		
SE-Area ("SO-Bezirk")	OlyTK 8		M4 (1.17)	
	OlyTK 9	M4 (1.25)		
	OlyTK 20, 20rep			M4 (1.00, 1.06)
South Stoa	OlyTK 19			chemical loner
unknown	OlyTK 18			M4 (0.92)

Table 3: Average compositions of the ceramic bodies as determined with SEM-EDS: Each value corresponds to at least three different measurements of sufficiently flat areas of typically 200×200 μm^2 up to 500×500 μm^2.

	Oly GM 3	**Oly GM 5**	**Oly GM 6**	**Oly GM 8**	**Oly GM 22**	**Oly GM 24**	**Oly GM 43**	**Oly GM 45**	**Oly GM 51a**	**Oly GM 51b**	**Oly GM 61**	**Kal GM 100**	**Kal GM 101**	**Kal GM 103**	**Kal GM 104**
Na_2O	3.9	2.3	3.9	9.9	6.4	5.0	2.9	3.4	5.0	3.1	0.1	0.7	1.4	2.1	1.9
MgO	2.9	4.9	2.6	3.5	2.9	1.9	2.5	1.9	2.6	2.8	3.3	3.0	4.0	2.3	2.7
Al_2O_3	17.4	15.9	14.3	10.5	11.3	11.2	9.1	7.9	4.9	5.5	5.3	14.8	7.2	16.8	13.2
SiO_2	43.1	41.0	49.8	34.8	31.5	32.1	29.0	26.8	24.9	23.8	77.7	46.1	21.6	46.8	39.3
P_2O_5	0.7	0.7	0.6	0.2	2.3	1.4	1.1	1.8	1.9	2.2	0.2	0.6	2.1	0.3	1.7
SO_3	0.6	1.1	0.2	0.8	1.3	0.5	1.1	1.1	5.2	4.5	0.4	0.6	1.6	0.5	0.2
Cl_2O	0.1	0.2	0.3	0.9	0.2	0.2	0.4	0.4	0.2	0.5	0.4	0.1	0.7	0.2	0.1
K_2O	2.5	1.6	2.2	0.4	0.6	0.6	1.6	0.8	0.7	1.1	1.0	2.3	1.4	2.3	1.1
CaO	8.1	10.3	4.4	16.4	14.4	19.5	36.8	34.9	15.3	29.6	0.5	12.1	49.9	9.1	23.9
BaO	0.1	0.3	0.1	0.1	n.d.	1.0	0.4	0.9	0.1	0.4	n.d.	0.1	0.7	0.1	0.0
TiO_2	0.7	1.0	1.0	0.5	0.6	n.d.	0.6	0.5	0.6	0.5	0.8	0.7	0.7	0.9	0.5
Fe_2O_3	7.4	11.2	9.4	5.2	4.9	7.7	5.2	6.3	9.3	6.5	5.1	8.9	4.5	13.5	4.9
CuO	6.7	2.4	3.4	1.0	9.5	3.3	3.9	4.4	6.5	7.2	3.7	7.0	1.2	2.9	8.0
ZnO	3.2	1.2	6.3	14.1	10.5	11.8	3.1	5.8	20.0	9.2	0.5	0.3	0.6	0.4	0.3
PbO	2.7	6.0	1.7	1.6	3.5	3.6	2.2	3.1	2.7	3.2	1.1	2.8	2.5	1.8	2.1

Table 4: Composition of metal remains in the ceramic body as measured by SEM-EDS: The approximate size of the analysed area is indicated in the second line.

	OlyGM05	**OlyGM06**	**OlyGM51**	**OlyGM61**	**OlyGM61**	**KalGM101**	**KalGM103**	**KalGM104**
	100x100 µm2	*30x30 µm2*	*10x30 µm2*	*30x50 µm2*	*30x50 µm2*	*10x10 µm2*	*10x10 µm2*	*20x20 µm2*
O	2,9	15,2	0,5	7,3	18,1	19,6	8,1	19,2
Na	1,1	5,2	0,2	0,8	1,9	1,8	1,3	1,3
Mg	0,6	0,2	*n.d.*	1,0	0,7	1,5	0,8	1,9
Al	1,3	1,8	0,1	1,1	2,2	2,3	5,5	5,2
Si	3,0	6,1	0,2	2,5	7,7	5,7	9,8	15,3
P	0,4	0,2	*n.d.*	0,6	0,3	0,4	0,1	0,7
S	1,0	0,2	0,1	11,2	0,5	0,6	0,2	0,4
Cl	0,2	1,0	0,9	1,5	0,4	0,4	0,2	0,5
K	0,2	0,3	0,1	*n.d.*	0,6	0,3	0,8	1,1
Ca	0,6	0,4	1,7	0,1	0,4	8,9	1,6	4,5
Fe	1,0	1,0	7,2	0,7	1,5	1,5	4,5	3,2
Cu	71,9	60,8	72,7	1,6	59,0	51,3	64,6	41,6
Zn	2,6	4,4	5,9	*n.d.*	1,3	0,6	0,5	0,3
Pb	11,9	2,2	8,6	71,5	4,4	4,7	1,6	2,9

Table 5: Clay cores and mould residues adhering to tripod fragments found at Olympia and Kalapodi, and comparative material from Olympia and Kalapodi: Average concentrations M of the elemental concentration groups in µg/g (ppm), if not indicated otherwise, and spreads σ (root mean square deviations) in percent of M for 32 elements. Each individual dataset (s. appendix 2*) has been corrected for dilution or enhancement by its best relative fit factor (s. Tab. 1)* with respect to the average value M of its group. Values are missing, if the uncertainty or/and the spread is larger than the value itself. The * designates the reduced set of 14 elements used here for the calculation of the best relative fit factors, whereas for grouping of pottery vessels usually the full set of the 25 elements is taken that are underlined.

	M1 15 samples		M4 24 samples		M5 10 samples		M2 4 samples	
	M	±σ(%)	M	±σ(%)	M	±σ(%)	M	±σ(%)
As	54.4	57.	--		--		--	
Au	--		0.026	61.	--		0.027	39.
Ba	340.	21.	390.	13.	284.	38.	362.	29.
Br	3.88	30.	3.12	53.	6.55	83.	2.93	34.
Ca %	5.79	33.	7.93	47.	8.89	48.	5.83	39.
Ce*	65.4	4.1	58.2	4.9	36.4	4.8	54.8	3.3
Co	38.9	62.	48.5	71.	70.2	73.	63.2	46.
Cr	195.	40.	184.	27.	209.	16.	485.	1.9
Cs	2.85	46.	3.55	41.	2.06	36.	11.4	57.
Cu %	1.90	63.	2.26	62.	2.40.	72.	2.55	65.
Eu*	1.16	4.1	1.14	3.9	0.74	5.7	1.12	3.4
Fe* %	3.47	9.0	4.31	11.	2.49	11.	5.66	26.
Ga	13.4	46.	16.7	64.	9.42	37.	16.7	15.
Hf*	5.82	12.	3.88	10.	3.36	9.5	4.08	2.8
K %	1.30	35.	1.67	36.	0.94	30.	0.98	28.
La*	31.0	3.9	28.8	4.0	18.3	3.7	26.1	5.5
Lu*	0.45	12.	0.45	22.	0.42	31.	0.46	6.9
Na %	1.25	37.	0.99	52.	0.71	35.	1.40	45.
Nd*	24.5	8.5	24.5	9.4	17.7	16.	23.8	11.
Ni	179.	58.	167.	41.	146.	25.	351.	9.7
Rb	51.4	57.	74.6	45.	41.4	33.	75.1	42.
Sb	3.12	71.	1.86	79.	3.42	98.	4.23	99.
Sc*	12.7	9.8	15.7	5.4	8.89	9.3	21.1	4.4
Sm*	4.75	7.6	4.74	5.4	3.09	8.4	4.96	2.4
Ta*	0.81	6.8	0.72	9.0	0.43	19.	0.66	6.4
Tb*	0.74	7.5	0.69	12.	0.48	16.	0.71	9.0
Th*	10.1	8.8	9.74	7.1	5.66	7.8	8.99	1.6
U*	2.12	15.	1.93	24.	1.28	22.	2.56	13.
W	19.1	96.	13.6	47.	--		27.3	32.
Yb*	2.69	9.1	2.50	9.6	1.63	11.	2.48	10.
Zn	6659	99.	--		19140.	77.	4420.	87.
Zr	207.	21.	144.	19.	103.	25.	147.	18.

	M3 12 samples		M7 7 samples		M6 19 samples	
	M	±σ(%)	M	±σ(%)	M	±σ(%)
As	--		15.8	39.	4.71	26.
Au	0.51	80.	0.014	74.	0.004	28.
Ba	268.	35.	255.	14.	174.	26.
Br	2.16	33.	3.79	73.	6.06	40.
Ca %	19.7	11.	4.05	64.	12.6	12.
Ce*	30.0	3.8	43.9	7.4	27.5	2.8
Co	27.6	50.	19.4	13.	31.3	5.1
Cr	183.	19.	291.	30.	567.	5.9
Cs	4.19	52.	2.42	24.	1.80	9.2
Cu %	1.30	46.	--		0.026.	52.
Eu*	0.60	9.2	0.82	3.2	0.56	2.4
Fe* %	2.47	5.2	3.19	2.4	3.41	2.6
Ga	9.36	33.	26.8	42.	13.8	29.
Hf*	1.91	7.4	4.49	3.9	2.41	6.4
K %	0.58	36.	1.40	44.	0.98	8.4
La*	15.4	3.8	19.4	3.0	12.7	2.7
Lu*	0.24	16.	0.31	7.6	0.22	8.7
Na %	0.84	45.	0.70	27.	0.52	5.0
Nd*	12.6	14.	19.5	20.	9.38	13.
Ni	186.	32.	121.	27.	551.	7.4
Rb	25.5	53.	64.8	11.	40.8	9.2
Sb	79.3	99.	0.47	12.	0.30	19.
Sc*	8.52	4.5	11.1	3.6	12.0	2.3
Sm*	2.39	5.9	--		1.83	2.5
Ta*	0.37	11.	0.53	14.	0.42	7.4
Tb*	0.38	13.	0.59	11.	0.37	11.
Th*	4.87	4.9	6.91	2.8	4.33	2.2
U*	1.14	23.	1.61	28.	0.87	16.
W	3.77	92.	--		2.73	16.
Yb*	0.94	38.	2.13	3.9	1.38	3.4
Zn	6925.	78.	61.2	16.	59.3	4.4
Zr	87.3	22.	150.	17.	87.4	20.

§correct for the samples from tripods, for the samples of the technical material in this group the value is lower: 529 ± 53 %

Table 6: Provenances of tripods excavated at Olympia and Kalapodi.
O tripod manufactured at Olympia (NAA groups M1 / M3 / M4 / M5)
K tripod manufactured at Kalapodi (NAA group M6)
L tripod of unknown provenance (chemical loner)
X NAA-group M2 (manufactured neither at Olympia nor at Kalapodi)

phase	excavated at Olympia	excavated at Kalapodi
3 (ca. 975-925 BC)	O O L	O
4 (ca. 925-850 BC)	O O X X X L L	
5 (ca. 850-800 BC)	O O O O O O O O O O O O L L L	O O K
6 (ca. 800-750 BC)	O O O O O O O O O O L L	O
7 (ca. 750-700 BC)	O O O L L L	

Supplementary Table 1: List of the 66 samples taken from clay cores and mould–residues adhering to tripod legs and handles

Fragments excavated at Kalapodi are stored either in the Museums of Lamia or (B 2303) Atalanti, fragments excavated at Olympia are all stored in the Museum of Olympia.

Excavated at Kalapodi:

KalGM 100	B 1437	Felsch, 2007, cat. 2
KalGM 101	B 2650	Felsch, 2007, cat. 7
KalGM 102	B 1382	Felsch, 2007, cat. 10
KalGM 103	B 2303	Felsch, 2007, cat. 11
KalGM 104	B 643	Felsch, 2007, cat. 13

Excavated at Olympia:

OlyGM 1	B 47	Maaß, 1978, cat. 82
OlyGM 2	B 277	Maaß, 1978, cat. 187
OlyGM 3	B 745	Maaß, 1978, cat. 72
OlyGM 4	B 812	Willemsen, 1957, 22
OlyGM 5	B 1247	Maaß, 1978, cat. 73
OlyGM 6	B 1250	Willemsen, 1957, 20
OlyGM 8	B 1253	Maaß, 1978, cat. 178
OlyGM 9	B 1255	Maaß, 1978, cat. 176 a
OlyGM 10	B 1665	Maaß, 1978, cat. 117 aα
OlyGM 11	B 1666	Maaß, 1978, cat. 181 e
OlyGM 12	B 1730	Maaß, 1978, cat. 179
OlyGM 13	B 2130	Maaß, 1978, cat. 176 b
OlyGM 14	B 2131	Maaß, 1978, cat. 84 aα
OlyGM 15	B 2216	Maaß, 1978, cat. 181 f
OlyGM 16	B 2330	Maaß, 1978, cat. 114
OlyGM 17	B 2334	Maaß, 1978, cat. 111 a
OlyGM 18	B 2403	Maaß, 1978, cat. 123
OlyGM 19	B 2406	Maaß, 1978, cat. 128
OlyGM 20	B 2412	Willemsen, 1957, 25
OlyGM 21	B 2413	Maaß, 1978, cat. 176 c

OlyGM 22	Ol. IV Nr. 627	Maaß, 1978, cat. 116 b
OlyGM 23	B 2419	Maaß, 1978, cat. 183
OlyGM 24	B 2424	Maaß, 1978, cat. 97
OlyGM 25	B 2436	Maaß, 1978, cat. 113 a
OlyGM 26	B 4350	Maaß, 1978, cat. 110 a
OlyGM 27	B 4350	Maaß, 1978, cat. 110 a
OlyGM 29	B 4970	Maaß, 1978, cat. 12
OlyGM 30	B 6452	Maaß, 1978, cat. 93
OlyGM 32	B 6455	Maaß, 1978, cat. 95
OlyGM 33	B 7227	Maaß, 1978, cat. 47 b
OlyGM 34	B 7270	Maaß, 1978, cat. 49
OlyGM 35	B 10328	unpublished shaft–fragment
OlyGM 36	B 10397	unpublished rib–handle
OlyGM 37	BE 208	Maaß, 1978, cat. 119
OlyGM 38	Br 1642 + Br 1641	Maaß, 1978, cat. 100 a
OlyGM 39	Br 2104	Willemsen, 1957, 23
OlyGM 40	Br 3580 + B 2585	Maaß, 1978, cat. 108
OlyGM 41	Br 3622	Willemsen, 1957, 25
OlyGM 42	Br 3627	Maaß, 1978, cat. 104
OlyGM 43	Br 4635	Maaß, 1978, cat. 180 a
OlyGM 44	Br 5060	Maaß, 1978, cat. 185 c
OlyGM 45	Br 5177	Maaß, 1978, cat. 182
OlyGM 46	Br 5307	Maaß, 1978, cat. 99
OlyGM 47	Br 5319	Maaß, 1978, cat. 181 a
OlyGM 48	Br 5400	Maaß, 1978, cat. 100 b
OlyGM 49	Br 5976	Willemsen, 1957, 27
OlyGM 51	Br 7321	Maaß, 1978, cat. 5
OlyGM 52	Br 7535	Willemsen, 1957, 22
OlyGM 53	Br 8765	unpublished leg–fragment
OlyGM 54	Br 11555	Willemsen, 1957, 14
OlyGM 55	Br 12109	Maaß, 1978, cat. 181 b
OlyGM 56	Br 13039	Maaß, 1978, cat. 180 b
OlyGM 57	Br 13261	Maaß, 1978, cat. 87
OlyGM 58	Br 13379	unpublished leg–fragment

OlyGM 59	o. Nr.	Maaß, 1978, cat. 91
OlyGM 61	o. Nr.	Willemsen, 1957, 23
OlyGM 62	o. Nr.	Maaß, 1978, cat. 113 b
OlyGM 63	o. Nr.	Maaß, 1978, cat. 116 f
OlyGM 64	o. Nr.	Maaß, 1978, cat. 116 g
OlyGM 65	o. Nr.	Maaß, 1978, cat. 116 e
OlyGM 66	Ol. IV Nr. 565	Willemsen, 1957, 25

Supplementary Table 2: Clay cores and mould residues adhering to tripod fragments found at Olympia (OlyGM) and Kalapodi (KalGM), and technical ceramics found in Olympia (OlyTK) and Kalapodi (KalTK). Given are the raw concentration data C of 32 elements measured by NAA, University Bonn, in µg/g (ppm), if not indicated otherwise, and the average experimental uncertainties (statistical counting errors only), also in percent of C. Missing values are below the detection limit or not measured.

Sample	factor	As	Au	Ba	Br	Ca%	Ce	Co	Cr	Cs	Cu
OlyGM 1	1.000	15.6	0.015	570.	2.16	4.86	79.2	48.7	158.	2.11	11837.
OlyGM 2	1.000	69.1	0.14	269.	1.64	18.7	32.7	49.7	192.	3.46	7014.
OlyGM 3	1.000	45.2	0.017	437.	2.50	6.31	52.9	119.	162.	2.80	35936.
OlyGM 4	1.000	54.1	0.015	450.	1.92	7.36	57.6	54.8	507.	17.7	16107.
OlyGM 5	1.000	372.	0.023	221.	2.93	2.59	50.6	52.1	481.	2.73	31169.
OlyGM 6	1.000	60.1	0.014	349.	1.33	3.05	54.7	35.5	257.	3.84	22371.
OlyGM 8	1.000	95.8	0.13	364.	2.33	13.5	27.5	20.4	115.	0.97	9269.
OlyGM 9	1.000	184.	0.66	313.	2.55	19.4	31.6	33.1	165.	5.37	10414.
OlyGM 10	1.000	86.5	0.052	269.	5.31	7.66	53.5	29.2	186.	2.21	24455.
OlyGM 11	1.000	499.	0.46	206.	1.81	19.8	27.3	32.5	193.	6.74	19421.
OlyGM 12	1.000	712.	2.20	242.	3.72	12.6	25.8	21.8	177.	0.97	34117.
OlyGM 13	1.000	218.	0.60	67.1	1.35	19.1	27.7	13.3	190.	3.15	15564.
OlyGM 14	1.000	25.6	0.011	291.	3.57	5.30	77.2	38.4	383.	3.23	30133.
OlyGM 15	1.000	116.	0.37	327.	2.07	13.1	47.8	19.4	339.	6.90	14122.
OlyGM 16	1.000	65.4	0.21	512.	4.31	6.39	73.5	46.6	218.	4.42	16425.
OlyGM 17	1.000	129.	0.051	470.	5.06	7.01	56.7	78.8	174.	3.20	21583.
OlyGM 18	1.000	130.	0.25	199.	4.14	5.22	63.8	91.0	325.	0.82	53151.
OlyGM 19	1.000	123.	0.029	143.	8.87	2.14	24.3	131.	148.	1.84	67665.
OlyGM 20	1.000	67.5	0.059	469.	3.96	4.28	78.0	35.7	129.	5.30	13576.
OlyGM 21	1.000	276.	0.78	438.	1.42	10.6	28.4	17.6	198.	2.29	12755.
OlyGM 22	1.000	88.7	0.063	572.	2.79	10.8	44.5	63.3	251.	2.21	27203.
OlyGM 23	1.000	89.8	0.10	439.	2.12	14.3	40.9	29.8	220.	1.84	20748.
OlyGM 24	1.000	44.4	0.014	308.	1.18	11.8	42.8	19.7	151.	2.82	12538.
OlyGM 25	1.000	158.	0.020	339.	3.03	7.16	61.2	29.5	203.	2.14	32397.
OlyGM 26	1.000	68.5	0.010	304.	3.03	6.93	71.1	19.3	128.	1.78	14419.
OlyGM 27	1.000	38.5	0.018	497.	2.41	5.20	81.5	33.1	156.	5.45	13772.
OlyGM 29	1.000	8.88	0.012	82.8	2.53	35.0	10.4	47.9	25.6	0.33	2775.
OlyGM 30	1.000	56.7	0.042	465.	3.14	3.50	77.5	50.5	274.	3.65	22376.
OlyGM 32	1.000	32.4	0.046	427.	4.35	4.85	72.3	24.8	164.	2.83	14729.
OlyGM 33	1.000	29.1	0.031	366.	2.80	2.87	40.3	44.6	339.	1.81	31054.
OlyGM 34	1.000	31.0	--	262.	5.22	4.58	54.7	32.4	238.	0.70	29043.
OlyGM 35	1.000	118.	0.38	260.	2.40	17.2	29.9	13.1	205.	2.49	11752.
OlyGM 36	1.000	51.3	0.040	474.	3.73	8.20	59.7	439.	388.	4.64	15948.
OlyGM 37	1.000	85.8	0.15	264.	3.38	12.8	25.6	66.5	171.	1.85	28936.
OlyGM 38	1.000	24.1	0.034	591.	2.85	4.39	70.9	68.5	153.	1.94	21023.
OlyGM 39	1.000	38.0	0.035	493.	2.98	6.34	62.0	44.4	521.	11.1	9849.
OlyGM 40	1.000	237.	--	314.	5.72	4.73	43.7	40.0	214.	0.68	73793.
OlyGM 41	1.000	25.3	0.023	681.	3.72	5.33	84.2	41.4	179.	5.12	3022.
OlyGM 42	1.000	65.2	0.11	320.	3.94	7.60	69.8	40.7	145.	3.95	12577.
OlyGM 43	1.000	54.6	0.031	292.	2.19	21.5	32.1	38.0	138.	7.75	10966.
OlyGM 44	1.000	150.	0.48	357.	1.88	24.0	24.7	16.4	126.	3.56	9322.
OlyGM 45	1.000	471.	1.24	250.	1.45	18.3	24.4	24.6	126.	1.37	21367.
OlyGM 46	1.000	75.2	0.030	312.	3.78	2.86	46.9	89.8	95.7	1.74	87624.
OlyGM 47	1.000	381.	1.02	446.	2.60	17.0	30.1	19.0	248.	2.09	16764.

OlyGM 48	1.000	83.0	0.042	416.	2.71	6.96	64.5	33.2	173.	2.45	14609.
OlyGM 49	1.000	106.	0.20	376.	7.23	8.45	53.2	57.2	158.	1.91	40314.
Sample	**factor**	**As**	**Au**	**Ba**	**Br**	**Ca%**	**Ce**	**Co**	**Cr**	**Cs**	**Cu**
OlyGM 51	1.000	12.2	0.024	94.4	3.70	21.4	18.8	19.2	241.	1.79	16936.
OlyGM 52	1.000	107.	0.036	289.	3.85	7.07	50.2	96.0	438.	14.3	41073.
OlyGM 53	1.000	32.2	0.021	291.	4.54	4.85	70.1	32.3	111.	0.69	10598.
OlyGM 54	1.000	12.4	0.014	291.	2.00	7.76	55.5	24.8	214.	3.16	1809.
OlyGM 55	1.000	880.	2.27	144.	3.19	18.0	23.0	42.8	145.	1.32	67903.
OlyGM 56	1.000	74.0	0.070	281.	2.48	20.7	31.8	20.1	169.	7.29	4687.
OlyGM 57	1.000	54.0	0.19	384.	6.02	4.31	70.0	29.1	126.	3.69	25849.
OlyGM 58	1.000	23.6	0.012	286.	2.85	6.75	56.8	92.4	236.	1.22	11614.
OlyGM 59	1.000	64.0	0.041	398.	5.24	3.94	67.8	641.	266.	1.07	16388.
OlyGM 61	1.000	92.1	0.044	72.0	3.15	6.45	29.2	779.	35.2	2.56	66262.
OlyGM 62	1.000	58.8	0.051	357.	12.3	7.92	59.9	102.	136.	1.96	29333.
OlyGM 63	1.000	93.9	0.052	277.	9.67	9.56	45.5	127.	269.	0.58	34528.
OlyGM 64	1.000	119.	0.036	593.	15.2	7.40	46.3	84.3	199.	2.96	33609.
OlyGM 65	1.000	33.2	0.017	178.	5.68	8.23	25.5	106.	190.	1.46	37936.
OlyGM 66	1.000	33.5	0.071	584.	4.18	4.85	77.7	62.5	157.	3.82	20150.
KalGM 100	1.000	44.7	0.015	369.	5.48	5.16	62.4	24.8	203.	3.69	23373.
KalGM 101	1.000	9.39	0.004	103.	11.4	27.0	15.3	42.6	320.	1.40	1672.
KalGM 102	1.000	239.	0.25	217.	14.1	6.40	30.8	115.	161.	1.21	******
KalGM 103	1.000	18.7	0.007	477.	2.69	5.59	73.0	123.	116.	7.13	6533.
KalGM 104	1.000	319.	0.068	326.	3.37	11.4	46.7	16.7	112.	3.69	56993.
OlyTK 1	1.000	12.0	0.046	346.	5.14	8.61	44.6	18.5	198.	3.01	371.
OlyTK 2	1.000	15.8	0.015	263.	4.07	3.81	41.7	23.0	309.	2.54	459.
OlyTK 3	1.000	26.9	0.013	301.	9.25	2.77	41.8	20.6	286.	1.20	302.
OlyTK 4	1.000	11.7	0.007	205.	2.58	3.91	44.1	20.4	458.	2.67	312.
OlyTK 5	1.000	15.4	0.009	255.	2.40	3.59	46.7	17.4	301.	2.83	263.
OlyTK 6	1.000	17.0	0.009	278.	4.43	2.71	42.4	17.4	251.	2.26	347.
OlyTK 7	1.000	16.2	0.008	223.	0.55	1.89	51.7	18.0	207.	2.99	314.
OlyTK 8	1.000	12.0	0.025	299.	2.51	9.61	47.0	19.2	191.	2.90	380.
OlyTK 9	1.000	14.6	0.020	265.	2.24	9.77	43.4	23.1	187.	2.62	425.
OlyTK 10	1.000	8.96	0.012	357.	2.13	13.2	48.8	28.7	165.	3.71	262.
OlyTK 11	1.000	6.47	0.014	215.	3.26	10.7	41.3	17.7	235.	2.45	340.
OlyTK 12	1.000	3.62	0.009	208.	2.16	23.1	26.8	14.1	103.	1.40	257.
OlyTK 13	1.000	9.86	0.18	305.	1.61	9.13	45.0	19.4	185.	3.67	464.
OlyTK 14	1.000	13.8	0.022	318.	2.22	10.9	50.8	24.2	244.	4.36	402.
OlyTK 15	1.000	10.3	0.023	290.	2.07	3.31	50.6	29.5	176.	4.70	1016.
OlyTK 16	1.000	7.40	0.036	266.	3.25	9.48	39.4	18.6	221.	2.53	4323.
OlyTK 17	1.000	10.8	0.008	219.	1.88	8.10	34.2	14.8	205.	1.79	483.
OlyTK 18	1.000	6.27	0.017	406.	2.91	12.5	60.3	29.5	232.	6.20	1176.
OlyTK 19	1.000	22.6	0.024	264.	1.71	1.67	45.9	6.84	246.	2.35	966.
OlyTK 20	1.000	7.59	0.018	410.	1.24	7.28	57.4	26.9	240.	5.15	889.
OlyTK 20w	1.000	7.21	0.008	345.	1.88	9.55	54.8	24.4	220.	5.32	291.
KalTK 1	1.000	3.81	0.002	223.	4.86	12.9	28.6	32.6	609.	1.75	174.
KalTK 2	1.000	3.86	0.003	192.	9.30	14.7	26.5	31.1	554.	1.65	168.
KalTK 3	1.000	4.27	0.004	171.	5.02	12.6	27.7	32.7	605.	1.70	234.
KalTK 4	1.000	6.26	0.004	164.	5.40	15.5	25.8	31.1	554.	1.70	160.
KalTK 5	1.000	5.69	0.003	293.	3.56	11.8	29.5	31.9	581.	1.84	303.
KalTK 6	1.000	3.75	0.004	185.	6.25	12.0	26.4	31.7	598.	1.80	182.
KalTK 7	1.000	7.00	0.005	129.	3.20	11.9	29.1	29.3	578.	1.76	187.
KalTK 8	1.000	3.14	0.004	212.	6.22	13.2	25.9	28.9	563.	1.57	177.
KalTK 9	1.000	4.81	0.003	104.	4.12	18.6	21.5	24.0	461.	1.26	176.

KalTK 10	1.000	5.04	0.005	207.	5.25	13.0	26.6	30.1	565.	1.70	199.
KalTK 11	1.000	3.29	0.005	146.	11.9	12.4	26.2	30.8	541.	2.08	221.
KalTK 12	1.000	4.50	0.005	221.	3.73	11.2	29.6	35.4	533.	1.99	440.
Sample	**factor**	**As**	**Au**	**Ba**	**Br**	**Ca%**	**Ce**	**Co**	**Cr**	**Cs**	**Cu**
KalTK 13	1.000	4.49	0.004	136.	6.29	11.8	26.9	33.5	578.	1.75	702.
KalTK 14	1.000	4.82	0.004	164.	4.69	11.9	27.5	31.2	563.	1.78	246.
KalTK 15	1.000	3.82	0.005	170.	9.78	11.9	28.2	33.0	534.	2.15	397.
KalTK 16	1.000	5.14	0.003	127.	4.19	12.6	29.7	32.1	576.	1.81	243.
KalTK 17	1.000	3.36	0.004	136.	7.42	12.1	28.2	29.9	565.	2.00	255.
KalTK 18	1.000	7.17	0.007	115.	7.20	13.6	27.3	31.3	514.	1.95	1400.
ave. error		0.36	0.002	49.	0.38	0.23	0.39	0.28	1.1	0.11	109.
in %		0.4	1.6	16.	9.4	2.2	0.9	0.5	0.4	3.7	0.7
Sample	**factor**	**Eu**	**Fe%**	**Ga**	**Hf**	**K%**	**La**	**Lu**	**Na%**	**Nd**	**Ni**
OlyGM 1	1.000	1.45	5.97	15.0	4.78	2.14	38.2	0.49	0.86	28.5	139.
OlyGM 2	1.000	0.66	2.62	12.2	2.11	0.49	16.9	0.23	0.21	11.9	206.
OlyGM 3	1.000	1.04	3.61	12.1	3.79	1.78	25.7	0.43	0.96	20.6	35.2
OlyGM 4	1.000	1.20	5.27	19.4	4.15	0.84	27.5	0.47	1.18	22.8	393.
OlyGM 5	1.000	1.04	7.65	12.9	3.92	0.87	23.3	0.46	2.27	20.9	364.
OlyGM 6	1.000	1.14	3.92	15.3	5.13	1.70	26.5	0.57	1.35	27.9	220.
OlyGM 8	1.000	0.57	2.73	9.28	1.91	0.32	15.4	1.00	0.50	20.8	182.
OlyGM 9	1.000	0.77	2.40	12.4	1.84	0.91	16.2	0.27	0.62	13.8	162.
OlyGM 10	1.000	1.03	3.21	16.3	5.03	0.96	25.0	0.43	1.49	18.0	174.
OlyGM 11	1.000	0.54	2.17	12.2	1.84	0.39	14.0	0.16	1.08	11.6	137.
OlyGM 12	1.000	0.52	2.33	--	1.68	0.48	9.68	0.27	0.57	12.8	126.
OlyGM 13	1.000	0.51	2.29	11.2	1.68	0.47	14.2	0.26	1.54	14.2	80.3
OlyGM 14	1.000	1.22	3.65	17.2	6.91	1.30	32.6	0.43	1.57	24.6	250.
OlyGM 15	1.000	0.93	3.78	18.6	2.87	0.69	24.2	0.31	1.34	18.9	218.
OlyGM 16	1.000	1.98	5.01	23.6	3.07	2.10	38.0	0.67	0.44	40.2	318.
OlyGM 17	1.000	1.04	5.34	20.0	3.51	0.78	27.7	0.60	2.31	23.9	146.
OlyGM 18	1.000	1.12	3.88	13.3	7.23	0.79	30.5	0.53	0.57	27.3	382.
OlyGM 19	1.000	0.53	8.55	8.22	2.08	0.83	12.3	0.58	0.55	10.7	110.
OlyGM 20	1.000	1.40	4.16	22.7	5.30	2.69	37.8	0.57	1.53	28.5	86.5
OlyGM 21	1.000	0.55	2.37	--	1.94	0.48	8.10	0.34	0.14	17.7	126.
OlyGM 22	1.000	0.83	2.96	6.83	4.35	0.85	22.2	0.71	1.16	21.2	159.
OlyGM 23	1.000	0.85	4.19	25.5	2.86	0.85	21.1	0.68	0.51	17.2	209.
OlyGM 24	1.000	0.97	3.20	19.5	2.82	0.79	23.3	0.62	0.27	17.9	204.
OlyGM 25	1.000	1.12	4.43	25.5	4.00	1.19	30.1	0.68	0.41	27.8	184.
OlyGM 26	1.000	1.31	3.67	21.7	5.91	0.96	34.6	0.47	1.54	24.6	97.3
OlyGM 27	1.000	1.50	5.25	23.3	4.81	2.62	39.8	0.53	1.37	31.6	102.
OlyGM 29	1.000	0.21	0.48	1.15	0.40	0.17	4.59	0.046	0.18	4.69	119.
OlyGM 30	1.000	1.22	4.49	6.64	6.86	1.18	32.6	0.44	0.87	29.1	262.
OlyGM 32	1.000	1.35	3.78	21.4	5.61	1.94	34.7	0.45	1.37	26.5	181.
OlyGM 33	1.000	0.74	2.82	5.40	6.11	1.14	18.1	0.32	1.08	16.5	84.9
OlyGM 34	1.000	1.09	4.19	2.41	4.29	0.81	26.5	0.36	2.09	28.5	168.
OlyGM 35	1.000	0.59	2.58	8.28	1.80	0.36	14.6	0.19	1.12	14.2	268.
OlyGM 36	1.000	1.01	6.82	13.0	4.48	1.16	29.4	0.42	1.55	27.9	343.
OlyGM 37	1.000	0.55	1.72	6.01	2.39	0.72	13.0	0.28	0.57	15.3	88.1
OlyGM 38	1.000	1.27	5.82	18.3	4.17	2.44	34.6	0.52	1.13	32.3	188.
OlyGM 39	1.000	1.22	5.18	17.7	4.67	1.52	30.0	0.46	1.13	29.7	353.
OlyGM 40	1.000	0.73	9.42	8.16	3.60	0.60	20.2	0.46	0.17	21.0	87.9
OlyGM 41	1.000	1.57	5.48	21.6	5.18	2.64	41.0	0.56	0.95	39.1	177.
OlyGM 42	1.000	1.20	3.58	11.1	5.48	1.09	32.7	0.58	1.72	28.8	--

OlyGM 43	1.000	0.63	2.41	8.32	2.02	0.87	17.0	0.27	0.96	13.0	182.
OlyGM 44	1.000	0.52	2.20	6.59	1.64	0.70	12.7	0.21	0.49	10.7	254.
OlyGM 45	1.000	0.45	2.25	3.69	1.57	0.30	12.6	0.27	0.66	13.3	148.
OlyGM 46	1.000	0.87	3.67	4.34	2.78	1.53	22.5	0.34	0.75	18.7	151.
Sample	**factor**	**Eu**	**Fe%**	**Ga**	**Hf**	**K%**	**La**	**Lu**	**Na%**	**Nd**	**Ni**
OlyGM 47	1.000	0.59	2.68	4.19	2.27	0.59	15.5	0.26	0.80	12.3	238.
OlyGM 48	1.000	1.15	3.18	4.90	5.04	1.14	31.3	0.52	1.26	28.2	71.9
OlyGM 49	1.000	0.98	3.55	4.58	3.78	0.43	26.2	0.48	1.11	21.5	128.
OlyGM 51	1.000	0.43	1.15	--	1.80	0.37	10.1	0.22	0.19	9.20	125.
OlyGM 52	1.000	1.03	4.51	16.9	3.66	0.76	24.1	0.45	1.00	22.1	295.
OlyGM 53	1.000	1.29	3.11	7.03	6.91	1.02	33.8	0.57	1.30	30.4	118.
OlyGM 54	1.000	1.03	3.02	9.29	5.90	1.24	28.3	0.35	0.58	21.4	107.
OlyGM 55	1.000	0.43	1.94	--	1.57	0.34	11.8	0.16	0.71	8.27	144.
OlyGM 56	1.000	0.62	2.40	9.63	1.84	0.90	16.5	0.32	0.48	11.1	185.
OlyGM 57	1.000	1.27	3.18	17.9	6.95	1.61	33.8	0.48	1.75	26.3	94.7
OlyGM 58	1.000	1.00	3.19	12.0	5.45	0.69	28.4	0.40	0.54	22.1	161.
OlyGM 59	1.000	1.19	7.62	12.1	7.18	1.11	33.1	0.52	1.86	32.6	256.
OlyGM 61	1.000	0.67	1.80	--	0.90	0.50	12.5	0.44	0.41	17.5	256.
OlyGM 62	1.000	1.11	3.92	16.3	4.19	1.13	29.5	0.42	1.35	24.2	48.4
OlyGM 63	1.000	0.90	3.00	--	4.04	0.58	23.4	0.74	0.29	22.0	216.
OlyGM 64	1.000	0.88	3.66	20.1	3.64	1.20	23.0	0.73	1.25	26.7	250.
OlyGM 65	1.000	0.55	1.79	6.72	2.48	0.89	13.2	0.36	0.50	13.1	102.
OlyGM 66	1.000	1.43	5.07	27.6	4.69	2.44	38.3	0.58	0.98	28.1	118.
KalGM 100	1.000	1.03	3.54	26.1	5.44	1.70	28.7	0.37	1.01	20.9	159.
KalGM 101	1.000	0.29	1.61	--	1.17	0.54	6.91	0.099	0.29	4.07	253.
KalGM 102	1.000	0.57	2.17	8.72	2.28	0.98	14.5	0.22	0.63	10.2	446.
KalGM 103	1.000	1.36	6.77	36.9	4.91	2.02	35.2	0.49	2.13	27.5	130.
KalGM 104	1.000	0.84	2.62	8.07	3.71	1.36	22.4	0.29	1.56	17.4	286.
OlyTK 1	1.000	0.96	3.36	21.1	3.51	1.57	21.4	0.31	0.84	20.2	135.
OlyTK 2	1.000	0.79	3.21	18.7	4.44	1.15	19.1	0.28	0.67	18.1	63.2
OlyTK 3	1.000	0.82	3.06	21.9	4.69	1.13	19.3	0.30	0.57	18.1	125.
OlyTK 4	1.000	0.82	3.15	27.1	4.33	1.26	18.9	0.31	0.68	22.1	106.
OlyTK 5	1.000	0.83	3.36	23.9	4.78	1.25	19.5	0.32	0.66	18.2	165.
OlyTK 6	1.000	0.82	3.33	47.3	4.53	1.53	19.0	0.33	0.68	17.9	125.
OlyTK 7	1.000	0.85	3.19	38.7	4.40	1.22	20.9	0.30	0.57	23.5	128.
OlyTK 8	1.000	1.00	3.55	--	3.64	1.48	23.6	0.31	0.77	18.6	175.
OlyTK 9	1.000	0.91	3.07	38.2	3.72	1.48	21.5	0.31	0.80	18.7	168.
OlyTK 10	1.000	1.05	3.24	32.5	2.60	1.69	26.2	0.37	0.28	26.8	210.
OlyTK 11	1.000	0.84	2.36	24.6	4.67	1.21	20.6	0.31	0.70	24.1	161.
OlyTK 12	1.000	0.56	1.47	--	1.80	1.18	14.3	0.12	0.28	13.7	141.
OlyTK 13	1.000	0.93	3.36	67.4	3.31	2.66	22.4	0.28	0.76	21.3	188.
OlyTK 14	1.000	1.05	4.01	99.2	3.28	1.76	25.7	0.41	0.67	25.1	204.
OlyTK 15	1.000	0.99	3.49	134.	3.36	1.61	23.4	0.34	0.50	17.6	220.
OlyTK 16	1.000	0.80	3.06	105.	4.25	3.39	19.0	0.30	1.11	19.2	138.
OlyTK 17	1.000	0.74	2.50	105.	3.16	--	17.2	0.23	0.76	10.3	97.0
OlyTK 18	1.000	1.32	4.51	113.	3.51	2.83	31.9	0.49	0.67	28.3	281.
OlyTK 19	1.000	0.94	4.20	231.	4.69	4.36	26.9	0.41	0.33	18.8	233.
OlyTK 20	1.000	1.12	4.38	--	3.99	2.73	28.7	0.40	0.99	21.9	266.
OlyTK 20w	1.000	1.06	4.19	22.3	3.79	2.13	26.8	0.40	0.85	22.5	218.
KalTK 1	1.000	0.58	3.53	15.4	2.31	0.98	13.3	0.24	0.54	9.84	601.
KalTK 2	1.000	0.53	3.28	11.7	2.21	0.88	12.3	0.23	0.49	10.6	514.
KalTK 3	1.000	0.56	3.65	14.8	2.59	0.91	13.0	0.25	0.56	9.10	546.
KalTK 4	1.000	0.55	3.27	13.1	2.19	0.94	12.0	0.21	0.49	9.15	555.

KalTK 5	1.000	0.58	3.56	13.2	2.73	1.10	13.4	0.24	0.51	10.1	550.
KalTK 6	1.000	0.54	3.39	11.5	2.43	0.91	12.2	0.21	0.52	9.28	570.
KalTK 7	1.000	0.60	3.59	11.8	2.43	1.21	13.3	0.24	0.53	10.8	489.
KalTK 8	1.000	0.51	3.20	17.9	2.09	0.85	11.5	0.20	0.46	8.58	512.
KalTK 9	1.000	0.45	2.81	9.55	2.16	0.93	9.83	0.17	0.44	7.76	431.
Sample	**factor**	**Eu**	**Fe%**	**Ga**	**Hf**	**K%**	**La**	**Lu**	**Na%**	**Nd**	**Ni**
KalTK 10	1.000	0.55	3.47	9.11	2.45	1.00	12.2	0.22	0.52	9.51	599.
KalTK 11	1.000	0.55	3.34	11.3	2.39	0.93	11.9	0.23	0.47	8.95	555.
KalTK 12	1.000	0.59	3.45	24.1	2.53	1.14	13.6	0.27	0.55	11.6	576.
KalTK 13	1.000	0.55	3.35	8.99	2.27	0.89	12.4	0.22	0.52	8.09	629.
KalTK 14	1.000	0.58	3.52	20.8	2.35	0.99	12.7	0.19	0.53	9.88	539.
KalTK 15	1.000	0.55	3.49	11.1	2.31	1.00	12.8	0.18	0.49	8.50	529.
KalTK 16	1.000	0.58	3.63	23.0	2.64	1.03	14.0	0.25	0.56	9.66	577.
KalTK 17	1.000	0.56	3.40	11.7	2.30	0.94	13.2	0.26	0.52	8.11	575.
KalTK 18	1.000	0.57	3.31	11.7	2.77	0.91	12.7	0.20	0.47	8.98	574.
ave. error		0.020	0.013	4.8	0.058	0.14	0.097	0.017	0.016	2.4	33.
in %		2.3	0.4	35.	1.6	12.	0.4	4.6	1.9	13.	14.
Sample	**factor**	**Rb**	**Sb**	**Sc**	**Sm**	**Ta**	**Tb**	**Th**	**U**	**W**	**Yb**
OlyGM 1	1.000	63.3	1.66	20.6	5.71	1.02	0.97	14.0	2.64	18.5	3.25
OlyGM 2	1.000	21.5	26.5	9.16	2.33	0.35	0.43	5.45	0.93	--	1.36
OlyGM 3	1.000	68.6	2.60	13.5	4.29	0.56	0.53	8.91	2.94	--	2.12
OlyGM 4	1.000	81.6	2.00	22.9	5.01	0.65	0.70	9.56	3.06	--	2.81
OlyGM 5	1.000	33.5	10.6	20.0	4.83	0.68	0.71	8.70	2.34	--	2.06
OlyGM 6	1.000	87.3	1.98	15.7	5.01	0.80	0.84	9.62	2.15	--	2.47
OlyGM 8	1.000	8.90	8.14	9.60	3.16	0.39	0.45	4.74	1.32	--	1.12
OlyGM 9	1.000	44.5	53.8	9.17	2.39	0.39	0.41	5.02	1.13	--	1.02
OlyGM 10	1.000	30.0	1.85	11.9	3.96	0.71	0.72	8.04	2.17	--	2.44
OlyGM 11	1.000	16.3	120.	7.80	2.15	0.37	0.37	4.52	0.64	--	0.61
OlyGM 12	1.000	10.4	371.	7.63	2.68	0.28	0.21	4.26	1.56	3.28	2.13
OlyGM 13	1.000	10.2	68.3	8.10	2.18	0.37	0.29	4.61	1.39	--	0.70
OlyGM 14	1.000	49.2	1.80	13.4	4.89	0.92	0.76	12.8	2.01	--	2.59
OlyGM 15	1.000	39.4	29.0	13.4	3.60	0.65	0.55	7.73	1.88	--	1.74
OlyGM 16	1.000	75.9	2.95	19.1	8.41	0.64	1.07	11.1	4.49	--	3.58
OlyGM 17	1.000	37.5	3.43	15.0	4.94	0.74	0.53	10.0	1.51	--	2.12
OlyGM 18	1.000	19.7	4.79	12.7	4.83	0.76	0.78	10.1	2.59	--	2.57
OlyGM 19	1.000	51.0	4.03	6.93	2.33	0.23	0.58	3.92	2.80	--	1.01
OlyGM 20	1.000	107.	4.03	17.5	5.75	0.94	0.88	12.3	2.45	--	3.21
OlyGM 21	1.000	26.7	132.	8.66	2.59	0.36	0.48	4.72	0.62	3.66	0.35
OlyGM 22	1.000	37.7	10.7	10.5	3.82	0.73	0.62	7.03	1.17	--	1.85
OlyGM 23	1.000	34.5	5.75	14.4	3.51	0.61	0.60	6.94	1.99	--	2.01
OlyGM 24	1.000	28.9	1.00	12.6	3.83	0.59	0.70	7.24	1.78	--	2.13
OlyGM 25	1.000	33.7	3.16	15.5	5.04	0.77	0.64	10.7	3.03	--	2.44
OlyGM 26	1.000	34.1	1.63	13.2	4.67	0.89	0.84	10.8	2.51	--	3.16
OlyGM 27	1.000	86.4	1.51	20.9	5.49	1.01	0.84	14.0	2.38	--	3.37
OlyGM 29	1.000	8.69	0.65	1.37	0.75	0.058	0.12	1.24	6.04	70.5	0.20
OlyGM 30	1.000	54.5	2.43	13.2	5.31	0.96	0.83	13.6	2.12	47.2	2.34
OlyGM 32	1.000	45.1	1.49	15.9	5.32	0.88	0.80	10.7	2.45	5.52	3.18
OlyGM 33	1.000	50.7	2.56	9.46	3.17	0.42	0.49	6.63	1.81	17.0	1.61
OlyGM 34	1.000	26.4	1.22	16.0	4.98	0.70	0.68	9.42	1.60	9.16	1.79
OlyGM 35	1.000	16.2	34.0	8.67	2.31	0.34	0.35	5.01	1.20	2.95	0.81
OlyGM 36	1.000	83.1	1.84	13.3	5.44	0.56	0.63	9.92	2.03	10.8	2.51
OlyGM 37	1.000	37.1	5.88	6.17	2.18	0.28	0.41	3.77	1.00	92.9	0.93

OlyGM 38	1.000	62.6	1.44	19.6	5.93	0.94	0.74	13.2	2.45	19.4	3.09
OlyGM 39	1.000	84.4	1.31	22.1	5.62	0.73	0.77	9.76	2.66	37.0	2.89
OlyGM 40	1.000	9.55	3.71	10.4	3.89	0.52	0.60	7.04	2.25	14.3	1.36
OlyGM 41	1.000	101.	1.94	21.9	7.09	1.02	1.09	14.5	2.68	34.4	3.52
OlyGM 42	1.000	49.1	6.24	14.2	5.95	0.82	0.84	10.3	1.75	5.19	2.74
OlyGM 43	1.000	46.1	3.42	9.05	2.57	0.40	0.36	5.18	1.06	2.53	1.25
Sample	**factor**	**Rb**	**Sb**	**Sc**	**Sm**	**Ta**	**Tb**	**Th**	**U**	**W**	**Yb**
OlyGM 44	1.000	31.0	49.3	7.08	1.94	0.27	0.29	3.92	1.02	9.43	0.71
OlyGM 45	1.000	11.4	240.	6.87	2.30	0.28	0.39	3.93	0.67	0.93	1.54
OlyGM 46	1.000	33.4	3.01	11.3	3.52	0.57	0.43	7.56	1.84	86.4	1.43
OlyGM 47	1.000	20.1	96.7	8.30	2.55	0.47	0.38	4.85	0.97	2.33	0.71
OlyGM 48	1.000	42.0	4.61	11.0	5.24	0.71	0.70	9.40	2.11	2.40	2.71
OlyGM 49	1.000	23.0	3.98	12.6	4.36	0.71	0.60	8.89	2.39	3.84	1.80
OlyGM 51	1.000	17.2	0.42	4.88	1.52	0.19	0.27	2.82	1.09	8.99	1.04
OlyGM 52	1.000	100.	3.03	19.6	4.46	0.58	0.66	8.08	1.97	19.0	2.20
OlyGM 53	1.000	20.1	2.75	12.4	5.63	0.81	0.97	10.4	1.69	3.28	3.07
OlyGM 54	1.000	66.7	0.66	10.0	4.00	0.70	0.64	8.07	1.80	41.0	2.35
OlyGM 55	1.000	8.87	222.	6.39	2.12	0.27	0.30	3.70	1.57	2.95	0.14
OlyGM 56	1.000	49.3	9.01	9.18	2.32	0.35	0.44	5.00	1.46	2.57	1.24
OlyGM 57	1.000	63.3	4.58	13.3	5.09	0.92	0.84	10.8	2.86	13.8	3.40
OlyGM 58	1.000	16.2	0.68	10.2	4.12	0.74	0.59	8.35	2.23	39.5	2.54
OlyGM 59	1.000	27.0	1.69	11.9	5.84	0.58	0.83	10.6	2.62	15.7	2.94
OlyGM 61	1.000	15.3	2.41	3.49	3.50	0.40	0.48	2.81	0.88	19.8	1.07
OlyGM 62	1.000	34.4	2.85	15.1	4.48	0.72	0.60	9.97	1.30	12.3	2.52
OlyGM 63	1.000	14.9	1.74	9.87	4.35	0.47	0.47	7.47	1.83	5.46	1.97
OlyGM 64	1.000	51.4	3.10	11.8	4.27	0.53	0.43	7.32	1.32	5.83	2.06
OlyGM 65	1.000	38.0	2.03	6.34	2.17	0.25	0.38	3.78	1.09	38.6	1.22
OlyGM 66	1.000	89.1	1.89	20.3	6.12	0.95	0.82	13.4	2.09	24.7	3.19
KalGM 100	1.000	73.4	2.18	12.4	4.16	0.87	0.65	9.78	1.83	18.1	2.46
KalGM 101	1.000	27.2	0.31	5.73	0.90	0.18	0.18	2.33	0.24	12.7	0.70
KalGM 102	1.000	29.6	5.43	7.75	2.02	0.32	0.30	4.91	0.98	23.0	1.06
KalGM 103	1.000	128.	1.01	17.0	5.46	0.82	0.74	11.6	1.90	10.0	3.04
KalGM 104	1.000	85.2	6.26	10.4	3.02	0.55	0.49	7.32	1.41	7.12	1.76
OlyTK 1	1.000	79.8	0.43	12.5	--	0.55	0.67	7.57	1.67	--	2.28
OlyTK 2	1.000	71.4	0.54	11.0	--	0.37	0.52	6.67	1.27	--	2.07
OlyTK 3	1.000	52.5	0.49	10.1	--	0.47	0.58	6.49	1.61	--	2.11
OlyTK 4	1.000	67.5	0.43	11.3	--	0.56	0.57	6.97	1.57	--	2.05
OlyTK 5	1.000	62.7	0.43	11.8	--	0.63	0.55	7.12	2.10	--	2.23
OlyTK 6	1.000	63.5	0.42	11.1	--	0.58	0.65	7.11	2.37	--	2.12
OlyTK 7	1.000	64.4	0.52	11.2	--	0.57	0.64	7.41	1.04	--	2.08
OlyTK 8	1.000	74.6	0.50	12.8	--	0.55	0.65	7.92	1.84	--	2.26
OlyTK 9	1.000	65.2	0.50	12.4	--	0.53	0.72	6.91	1.32	--	2.21
OlyTK 10	1.000	83.3	0.49	14.1	--	0.45	0.62	7.64	1.71	--	2.36
OlyTK 11	1.000	58.0	0.80	8.64	--	0.54	0.58	6.09	1.41	--	2.02
OlyTK 12	1.000	39.3	0.36	6.36	--	0.28	0.43	3.89	1.02	--	1.31
OlyTK 13	1.000	88.1	2.70	12.2	--	0.53	0.58	7.30	1.61	--	2.19
OlyTK 14	1.000	104.	5.08	14.5	--	0.62	0.61	7.86	1.92	--	2.38
OlyTK 15	1.000	85.1	0.68	13.5	--	0.50	0.65	8.10	0.88	--	2.09
OlyTK 16	1.000	71.7	0.43	11.0	--	0.52	0.60	6.66	1.31	--	2.25
OlyTK 17	1.000	45.5	0.45	8.22	--	0.38	0.53	5.00	1.05	--	1.72
OlyTK 18	1.000	132.	0.69	19.1	--	0.60	0.83	9.83	1.81	--	2.83
OlyTK 19	1.000	54.7	0.58	14.5	--	0.74	0.71	9.57	2.38	--	2.72
OlyTK 20	1.000	123.	0.63	16.8	--	0.74	0.69	9.51	1.41	--	2.67

OlyTK 20w	1.000	122.	0.50	16.1	4.19	0.66	0.66	8.91	1.86	--	2.48
KalTK 1	1.000	38.2	0.27	12.6	1.98	0.44	0.40	4.44	0.92	2.82	1.35
KalTK 2	1.000	37.4	0.24	11.6	1.80	0.38	0.40	4.12	0.81	2.70	1.40
KalTK 3	1.000	42.4	0.43	12.7	1.97	0.48	0.38	4.53	1.06	2.62	1.44
KalTK 4	1.000	37.5	0.30	11.4	1.72	0.40	0.32	4.15	0.97	2.52	1.36
KalTK 5	1.000	43.6	0.27	12.5	1.93	0.50	0.48	4.68	0.84	4.06	1.48
KalTK 6	1.000	39.0	0.23	11.9	1.78	0.41	0.38	4.22	0.73	2.46	1.36
Sample	**factor**	**Rb**	**Sb**	**Sc**	**Sm**	**Ta**	**Tb**	**Th**	**U**	**W**	**Yb**
KalTK 7	1.000	46.6	0.40	12.5	2.01	0.48	0.41	4.52	1.08	3.24	1.52
KalTK 8	1.000	36.3	0.25	11.2	1.67	0.42	0.32	3.91	0.67	1.73	1.25
KalTK 9	1.000	31.4	0.23	9.80	1.41	0.36	0.29	3.37	0.69	2.15	1.03
KalTK 10	1.000	39.1	0.27	12.2	1.84	0.38	0.32	4.25	0.88	2.73	1.36
KalTK 11	1.000	43.0	0.25	11.8	1.74	0.41	0.35	4.10	0.63	2.81	1.34
KalTK 12	1.000	41.0	0.27	12.2	2.02	0.39	0.44	4.65	1.12	3.76	1.46
KalTK 13	1.000	38.4	0.29	11.7	1.74	0.39	0.37	4.35	0.86	2.47	1.36
KalTK 14	1.000	38.5	0.32	12.4	1.82	0.44	0.42	4.27	0.85	2.86	1.44
KalTK 15	1.000	44.8	0.29	12.0	1.81	0.46	0.36	4.32	0.93	2.41	1.29
KalTK 16	1.000	38.6	0.30	12.7	1.91	0.43	0.29	4.81	0.90	2.81	1.42
KalTK 17	1.000	45.7	0.27	11.9	1.84	0.41	0.36	4.41	0.85	2.30	1.45
KalTK 18	1.000	40.4	0.43	11.6	1.77	0.42	0.39	4.29	0.82	2.57	1.35
ave. error		2.6	0.28	0.018	0.033	0.045	0.063	0.068	0.29	0.30	0.074
in %		5.1	1.8	0.2	0.9	8.1	11.	0.9	18.	2.1	3.8
Sample	**factor**	**Zn**	**Zr**								
OlyGM 1	1.000	132.	177.								
OlyGM 2	1.000	697.	73.2								
OlyGM 3	1.000	10449.	160.								
OlyGM 4	1.000	350.	164.								
OlyGM 5	1.000	6985.	102.								
OlyGM 6	1.000	21878.	182.								
OlyGM 8	1.000	72599.	58.4								
OlyGM 9	1.000	5704.	87.8								
OlyGM 10	1.000	6080.	150.								
OlyGM 11	1.000	2139.	68.5								
OlyGM 12	1.000	13277.	103.								
OlyGM 13	1.000	11197.	68.1								
OlyGM 14	1.000	5388.	233.								
OlyGM 15	1.000	3624.	156.								
OlyGM 16	1.000	17440.	145.								
OlyGM 17	1.000	29025.	142.								
OlyGM 18	1.000	13344.	276.								
OlyGM 19	1.000	40873.	--								
OlyGM 20	1.000	9562.	129.								
OlyGM 21	1.000	18442.	43.3								
OlyGM 22	1.000	40157.	148.								
OlyGM 23	1.000	35518.	173.								
OlyGM 24	1.000	31677.	108.								
OlyGM 25	1.000	31700.	132.								
OlyGM 26	1.000	209.	180.								
OlyGM 27	1.000	127.	174.								
OlyGM 29	1.000	741.	80.6								
OlyGM 30	1.000	793.	247.								
OlyGM 32	1.000	274.	194.								

OlyGM 33	1.000	496.	183.								
OlyGM 34	1.000	269.	192.								
OlyGM 35	1.000	1402.	86.7								
OlyGM 36	1.000	110.	178.								
OlyGM 37	1.000	17032.	75.0								
OlyGM 38	1.000	5205.	191.								
OlyGM 39	1.000	2224.	180.								
OlyGM 40	1.000	21625.	165.								
Sample	**factor**	**Zn**	**Zr**								
OlyGM 41	1.000	5556.	209.								
OlyGM 42	1.000	20325.	220.								
OlyGM 43	1.000	8643.	95.6								
OlyGM 44	1.000	6604.	75.5								
OlyGM 45	1.000	18159.	55.7								
OlyGM 46	1.000	6462.	131.								
OlyGM 47	1.000	8719.	113.								
OlyGM 48	1.000	17164.	190.								
OlyGM 49	1.000	21149.	159.								
OlyGM 51	1.000	12348.	61.5								
OlyGM 52	1.000	7352.	136.								
OlyGM 53	1.000	16963.	286.								
OlyGM 54	1.000	4207.	240.								
OlyGM 55	1.000	4482.	72.6								
OlyGM 56	1.000	8755.	93.9								
OlyGM 57	1.000	326.	227.								
OlyGM 58	1.000	7265.	196.								
OlyGM 59	1.000	770.	279.								
OlyGM 61	1.000	18865.	--								
OlyGM 62	1.000	3856.	137.								
OlyGM 63	1.000	45114.	147.								
OlyGM 64	1.000	45212.	59.5								
OlyGM 65	1.000	18428.	53.0								
OlyGM 66	1.000	5635.	120.								
KalGM 100	1.000	238.	208.								
KalGM 101	1.000	73.6	49.9								
KalGM 102	1.000	177.	72.5								
KalGM 103	1.000	82.3	132.								
KalGM 104	1.000	139.	137.								
OlyTK 1	1.000	86.6	173.								
OlyTK 2	1.000	75.1	146.								
OlyTK 3	1.000	48.9	194.								
OlyTK 4	1.000	60.6	125.								
OlyTK 5	1.000	57.0	167.								
OlyTK 6	1.000	63.7	122.								
OlyTK 7	1.000	54.5	146.								
OlyTK 8	1.000	83.0	120.								
OlyTK 9	1.000	77.3	127.								
OlyTK 10	1.000	116.	122.								
OlyTK 11	1.000	65.4	133.								
OlyTK 12	1.000	98.3	45.6								
OlyTK 13	1.000	88.9	111.								
OlyTK 14	1.000	77.8	90.3								
OlyTK 15	1.000	109.	98.3								

OlyTK 16	1.000	68.3	150.								
OlyTK 17	1.000	49.4	92.3								
OlyTK 18	1.000	152.	149.								
OlyTK 19	1.000	71.8	149.								
OlyTK 20	1.000	103.	157.								
OlyTK 20w	1.000	99.9	139.								
KalTK 1	1.000	62.0	60.6								
KalTK 2	1.000	54.8	62.0								
KalTK 3	1.000	62.9	114.								
Sample	**factor**	**Zn**	**Zr**								
KalTK 4	1.000	54.0	79.9								
KalTK 5	1.000	65.1	112.								
KalTK 6	1.000	58.2	109.								
KalTK 7	1.000	61.8	90.1								
KalTK 8	1.000	54.6	61.5								
KalTK 9	1.000	48.7	85.1								
KalTK 10	1.000	57.4	86.7								
KalTK 11	1.000	59.3	82.2								
KalTK 12	1.000	60.8	101.								
KalTK 13	1.000	57.8	102.								
KalTK 14	1.000	59.2	95.3								
KalTK 15	1.000	62.9	68.7								
KalTK 16	1.000	60.6	73.6								
KalTK 17	1.000	56.8	109.								
KalTK 18	1.000	65.9	69.7								
ave. error		113.	24.								
in %		1.5	18.								