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STABLE LEAD ISOTOPE STUDIES OF BLACK SEA ANATOLIAN ORE SOURCES AND RELATED BRONZE AGE AND PHRYGIAN ARTEFACTS FROM NEARBY ARCHAEOLOGICAL SITES. APPENDIX: NEW CENTRAL TAURUS ORE DATA

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The accumulated published database of stable lead isotope analyses of ore and slag specimens taken from Anatolian mining sites that parallel the Black Sea coast has been augmented with 22 additional analyses of such specimens carried out at the National Institute of Standards and Technology. Multivariate statistical analysis has been used to divide this composite database into five separate ore source groups. Evidence that most of these ore sources were exploited for the production of metal artefacts during the Bronze Age and Phrygian Period has been obtained by statistically comparing to them the isotope ratios of 184 analysed artefacts from nine archaeological sites situated within a few hundred kilometres of these mining sites. Also, Appendix B contains 36 new isotope analyses of ore specimens from Central Taurus mining sites that are compatible with and augment the four Central Taurus Ore Source Groups defined in Yener et al. *(1991).*

KEYWORDS: BLACK SEA, CENTRAL TAURUS, ANATOLIA, METAL, ORES, ARTEFACTS, BRONZE AGE, MULTIVARIATE, STATISTICS, PROBABILITIES

INTRODUCTION

This is the third in a series of papers in which we have endeavoured to evaluate the present state of the application of stable lead isotope analyses of specimens from metallic ore sources and of ancient artefacts from Near Eastern sites to the inference of the probable origins of such artefacts. Our approach has been: (1) to bring into a common database all of the pertinent published lead isotope analyses of ores and artefacts; (2) to supplement these data with analyses carried out in our laboratories of specimens sought out to characterize more fully individual ore sources or types of artefacts; (3) to analyse statistically the ore data, when possible, into groups of specimens that seem reasonably to represent statistical samples of populations of individual ore sources; and then (4) to attempt to evaluate with what degree of probability individual artefacts correlate with these sources. The first of this series, Yener *et al.* (1991), was focused on metallic ore sources within the Taurus Mountains in south-central Anatolia; the second, Sayre

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et al. (1992), was more broadly concerned with ore sources throughout the Eastern Mediterranean region; and this paper focuses on ore sources from regions adjacent to the Black Sea coast in central and eastern Anatolia. Also, Appendix B includes a more complete characterization of the Central Taurus ore groups (Yener *et al.* 1991) based upon 36 new lead isotope analyses of Central Taurus ore specimens, which have been determined since these groups were originally defined.

COMMENTS ON CRITICISMS OF THE USE OF MULTIVATRIATE PROBABILITIES IN THE EVALUATION OF STABLE LEAD ISOTOPE DATA

A paper by Budd *et al.* (1995), which was critical of the use of stable lead isotope data for the determination of provenance of ancient metal objects, initiated a series of jointly published papers in which a number of questions concerning the lead isotope method were raised. We contributed to this round-table discussion (Sayre *et al.* 1995), and do not feel that the points raised at that time need be rehashed, although we shall comment on some more recent papers dealing with deviations from multivariate normality of the distributions of isotope ratios from individual ore sources. Rather, we want to point out that the answers to many of the questions raised earlier can best be derived from the lead isotope data themselves. The data presented in this paper, although only a fraction of the very extensive database of lead isotope measurements on ore sources and archaeological artefacts now in existence, are sufficiently representative of this database to provide some of these answers.

An example of such a question is whether the ores of a given mining region can be assumed to represent a single ore deposition. The North Central Anatolia and the Trabzon ore groups defined in this paper provide a definitive answer to this question. The isotope ratios of these two groups, listed in Table 7 (see Appendix A) and plotted in Figures 3 and 4, are obviously completely separate from one another. They must have resulted from different ore depositions. However, the map of their sites of origin (Fig. 2) shows that many of the specimens defining these two groups come from the same mining region situated immediately to the south and west of the city of Trabzon. Similar examples of ores with totally disparate isotope ratios occurring in the same mining regions, sometimes even within the same mines, can be found in the data dealing with ores from southern China and Western Europe. The data clearly indicate that multiple ore depositions can occur at a common site. It would also seem likely that the distribution of isotope ratios within an ore body whose deposition had continued throughout a very extended period of geological time might resemble that of a multiple deposition. Because of these possibilities, the isotope ratios ores of a given region might not be multivariately normally distributed, even if a single deposit laid down during a reasonably sharply defined geological period might be. Therefore, we do not believe that the isotopic ore groups that we have defined by means of multivariate probabilities are necessarily truly normally distributed, although some of them may be. We have not, to our recollection, ever claimed true normality for our groups, although some have assumed that our use of calculations based upon such normality has implied this. However, we have believed—and, for reasons we shall discuss, continue to believe—that multivariate probability calculations provide the most effective and practical evaluations and groupings of these data. Recently, Baxter and Gale (Baxter and Gale 1998; Baxter 1999) have presented univariate and multivariate statistical analyses of some of the ore source groups which indicated that their isotope ratios might not be normally distributed. Scaife and his coworkers (Scaife *et al.* 1996) have also raised the question as to whether such groups deviate from normality. The preceding comments would indicate that we agree that some of the groups may not be truly normal in distribution. However, because the ore deposits that were analysed might have had complex origins, the analyses do not prove that the isotope ratios of individual ore deposits inherently do not conform to normality. Baxter (1999) was careful to make the following observation concerning the significance of his conclusions: 'Common sense suggests that in many applications the normality assumption will not be critical. Either the sample will lie within the field, or will be so distant from it that it is obvious it could not come from it.' We shall elaborate upon this thought, and we point out that the groups we have defined have distributions that at least reasonably approximate normality. When this is the case, it is only those specimens with isotope ratios lying at the extremities of a group whose probabilities relative to that group might be shifted over the arbitrarily set inclusion limits because of deviations from normality within the group. The assignment of such peripheral specimens to a group is, at best, always ambiguous.

Multiple deposition in the same mining region would most probably result in isotopic distributions for that region with some degree of kurtosis. The degree to which such kurtosis might induce significant error in a multivariate normal approximation for assessing membership to a group can be estimated by considering Figure 1. In Figure 1 is presented a univariant description of a hypothetical double deposition of ore in the same region, each of which is assumed to be normally distributed, to produce a composite distribution for the region which has pronounced kurtosis. The two depositions are represented by two Gaussian curves with unit areas and unit standard deviations whose centers are separated by two standard deviations, and hence have been placed at plus one and minus one respectively. The composite sum of these two curves is the heavy dashed curve that shows considerable kurtosis. The manner in which the composite curve was formed results in its being centred about zero, with an area of two and a variance of two. This composite has therefore been approximately matched with a normal curve with average value of zero, an area of two and a standard deviation of the square root of two. The 95% containment limits for the matching normal distribution are indicated by vertical solid lines and the 95% containment limits for the composite distribution are indicated by the dotted vertical lines. The 95% containment limits of the matching normal distribution include 96.2% of

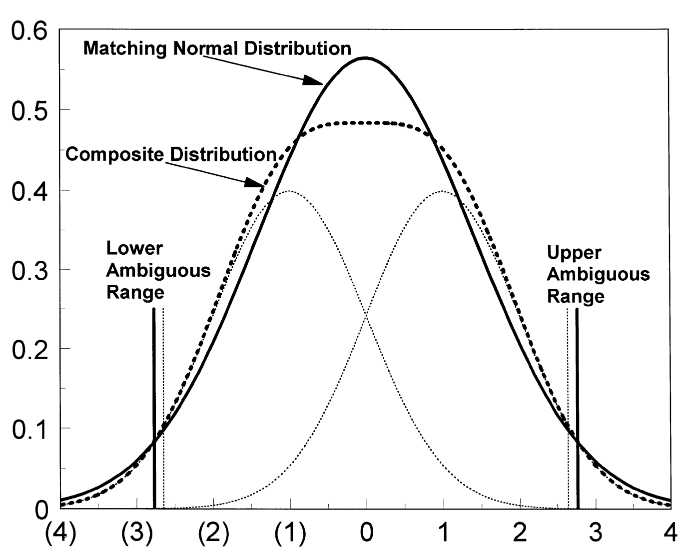

Figure 1 *A univariate comparison between a composite curve of two offset normal distributions and the overall normal distribution that most closely matches this composite.*

the composite distribution. Thus the inclusion difference in this instance only affects about 1% of the composite specimens. What is more important is that all of the specimens affected will have low normal curve probabilities that indicate that they lie in a concentration range for which assignment to the composite distribution would be inherently ambiguous. One must remember that inclusion limits are arbitrarily assigned, and that specimens that lie just within them are not significantly more likely to match the distribution to which they relate than specimens that lie just outside of them.

Common sense would suggest that this univariate example would reasonably reflect what would occur in an analogous trivariate situation. If a trivariate distribution that deviates from normality can be reasonably be approximated with a trivariate normal distribution, the trivariate probabilities calculated relative to the normal distribution should (1) identify all of the specimens that lie firmly within the deviant distribution with high probabilities, (2) identify all of the specimens that are well separated from the that distribution with negligibly small probabilities and (3) identify all specimens that are at the periphery of the distribution, and hence relate to it only ambiguously, with low probabilities. Also, one should expect that, for any arbitrarily selected inclusion limits, the number of specimens that would lie between the limits defined for the normal distribution and those that would more correctly apply to the deviant distribution would be relatively small. Such classification is all one can hope to obtain from the lead isotope data. One cannot expect the exact probabilities calculated to have precise meaning. We doubt that there is a more practical or more accurate method for obtaining such classification than mulitvariate probabilities.

Of course, an uneven sampling of two deposits in the same region would result in some skewness as well as kurtosis in their combined distribution. However, unless the sample of one deposit is greatly less than that of the other, the resulting skewness should not greatly complicate the arguments just presented. If the sample of one deposit is greatly larger that the other and the two distributions are significantly separate, it should be apparent both in appearance and in data handling that the smaller sample constitutes a separate shoulder appended to the greater sample. Another question concerning skewness—that is, whether the lead isotope data might be logarithmically distributed—is of no practical significance in the analysis of lead isotope ratio data, because with these data one is dealing with very small differences among relatively large values. The standard deviations of lead isotope ratios for most the ore source groups that have been proposed are only of the order of a tenth of 1% of the average ratios for those groups. This is in marked contrast with groups based upon trace impurity concentrations, in which the standard deviations can be as great as 50% of the average values. The relatively large spread in some of the trace impurity data groups makes the question of whether their data are normally distributed or are skewed to conform to log-normal distributions an important consideration. However, when such groups are narrow to the extent that their standard deviations are only 10–15% of the average values, it begins to make little difference whether one bases probability calculation for them on the assumption of normal or log-normal distributions. With the extremely narrow groups that one encounters with lead isotope data, the difference between probability calculations based on normal and log-normal distributions becomes truly insignificant. To demonstrate the extent to which this is true, we have calculated all of the probabilities listed in Table 1, first assuming trivariate normal distributions (the non-bracketed data) and then assuming trivariate log-normal distributions (the bracketed data). It is impressive how very nearly identical these sets of probabilities are. Because of the narrowness of the lead isotope groups, we could have carried out the entire data analysis of this paper assuming logarithmic skewness to exist in the data and none of the conclusions would have been altered significantly.

The degree to which compositional groups were indeed log-normally distributed was tested many times at Brookhaven National Laboratory, using multivariate methods for such evaluations. It was found repeatedly that the distributions of these groups were more nearly multivariately log-normal than normal. However, it was seldom possible to establish them to be fully log-normal, and it was for groups composed of some hundreds of specimens that the results of these tests could be regarded to be significant. We have not felt that any of the lead isotope groups have as yet been established with a sufficient number of specimens to permit effective mulitvariate analysis of their distributions.

Another of the questions raised whose answer can be found in the data themselves is whether lead deposits can be accompanied with deposits of other ores, notably those of copper, which carry the same isotope signatures as the lead deposits themselves. In considering this question, it should be recognized first that the formation of lead-rich veins is usually not a spatially isolated phenomenon, but one in which the entire region surrounding their location has been affected. Lead ore veins are often surrounded by regions that are called 'halos', in which the host rock is characterized by measurable enhancements of the concentrations of a number of chemical elements. These halos often extend to several hundred feet, sometimes as far as a kilometre, from the veins themselves. One of us has participated in an analytical mapping of such a halo (Panno *et al.* 1983; Panno, Harbottle and Sayre 1988). This was an analytical study of the concentrations of many trace elements within the host rock in the vicinity of the Buick Mine in south-east Missouri, which were determined, primarily, by means of neutron activation analysis using thermal neutrons. In this study a broad zone of enrichment was found to surround the lead-rich veins, which was defined primarily by the elements Mn, Fe, Zn, Br and Cl and, to a lesser extent by Na, K and As. Some of the enrichments were discernable as far removed from the veins as 0.5–1.0 km. Unfortunately, lead itself is not sensitive to activation with thermal neutrons, and hence lead concentrations were not determined in this study. One would expect, however, that lead would be among those elements whose concentrations would be enhanced in the vicinity of a lead ore.

The ore deposits of Turkey are known to be multimetallic, and ores of copper and other metals are often encountered in close association with lead ores. Table 7 (in Appendix A) shows that the North Central Anatolia, the Trabzon, the Artvin and the Küre ore groups all contain both lead ore specimens and copper ore specimens which have closely matching lead isotope ratios. The reason why the isotope ratios of the copper and lead ores within each group are so nearly identical might be that the two ores were essentially deposited together, or that the chemical processes relating to the formation of halos surrounding either of the separate ore deposits might have resulted in a preponderant transfer of lead into the copper ores. The formation of halos is a complex geochemical process, in which both extraction of elements from a host environment and deposition of elements into it can occur. It is possible that a deposition of copper into a lead-rich environment might have involved the leaching of lead out of the environment into the copper ore, or that the deposition of lead into a copper-rich environment could have resulted in an infusion of that lead into an existing copper ore. The published lead isotope data provide many other examples in which adjacent lead and copper ores have been found to be characterized by the same lead isotope ratios.

Our first endeavour has been to trace the full extent of mining regions whose mineral deposits are characterized by consistent lead isotope ratios, using the consistency of the data as the criterion for its inclusion. Some have argued that the selection data should be confined to those relating to sites at which there is clear evidence of ancient mining. We feel it is important to know the full extent of a region in which minerals with this characterization may be found, in part, because we doubt that all evidence of ancient mining throughout these regions has been, or ever will be, discovered. It is best first to determine, as well as one can, all possible sites from which the metal within an ancient object might have been derived and then to use the archaeological evidence that is available to infer which of these sites would have been more probable.

THE BLACK SEA METALLIC ORE AND SLAG SPECIMENS

The Black Sea ore specimens for which stable lead isotope measurements have been published previously include two specimens analysed in the 1960s at Brookhaven National Laboratory (Brill and Wampler 1967, and personal communication) 11 specimens analysed by Kouvo (1976) and entered into the United States Geological Survey Lead Isotope Data Bank, 40 specimens analysed at the Max-Planck-Institut für Chemie at Mainz (Seeliger *et al.* 1985; Wagner *et al.* 1986, 1992) and nine specimens analysed at the Tokyo National Research Institute of Cultural Properties (Hirao *et al.* 1995).

Our own Black Sea ore database of 22 specimens stems from ore and slag samples obtained during archaeo-metallurgical surveys of the Pontic Mountains during 1984–9. These surveys were conducted as a collaboration among the Turkish Geological Survey (Maden Tetkik Arama Genel Müdürlüğü), Boğaziçi University in Istanbul, the National Institute of Standards and Technology, and the Conservation Analytical Laboratory of the Smithsonian Institution. The area surveyed extended from the Gümüşhacıköy valley, situated about 20 km west of Merzifon, to the silver mines at Gümüşhane, south of Trabzon. This region is studded with galleries and open pit mines, from which most of the samples were taken. The discovery within slag deposits of Chalcolithic and Early Bronze Age pottery fragments and of charcoal fragments that produced fourth millennium BC radiocarbon dates provided evidence of the early exploitation of the mines (Kaptan 1978, 1984, 1986, 1991; Wagner *et al.* 1992). The presence of grinding tools and mortars with crushing and grinding hollows, as well as crucible fragments and metallurgical slags, at various sites throughout the region provided evidence that the ores from these mines were processed there. Samples were taken from as wide an area over this region as feasible, as well as from a variety of depths within ancient mines. Care was taken to identify features such as the age of the workings, whenever possible. The Black Sea ore studies have confirmed the prior reports of Turkish geologists that the ore depositional history of this region was complex (Ryan 1960; M.T.A. 1964, 1970, 1972, 1984; de Jesus 1980).

THE NORTH CENTRAL ANATOLIA AND TRABZON ORE SOURCE GROUPS

Ancient and modern mines located in an approximately 650 km long by about 100 km broad strip that roughly parallels and in the east joins the central Black sea coast of Anatolia, from about 90 km directly north of Ankara to slightly east of Trabzon (Fig. 2), have produced metallic ore and slag specimens that primarily fall into two distinctly separate, well characterized groups. Four specimens of native copper or azurite have been found at sites central to this region which have similar, exceptionally high ratios relative to lead 206. They do not, of course, form a group to which statistics can be usefully applied and will be considered separately. Figures 3 and 4 show how well the groups are formed and how well separated the three ore types are from each other in the full three-dimensional isotope ratio space. Two independent two-dimensional projections of the isotope data are required to demonstrate fully the isotope ratio clustering that might exist in the three-dimensional space. All separations among groups that are apparent in a two-dimensional projection of them will persist in the full three dimensions, but a

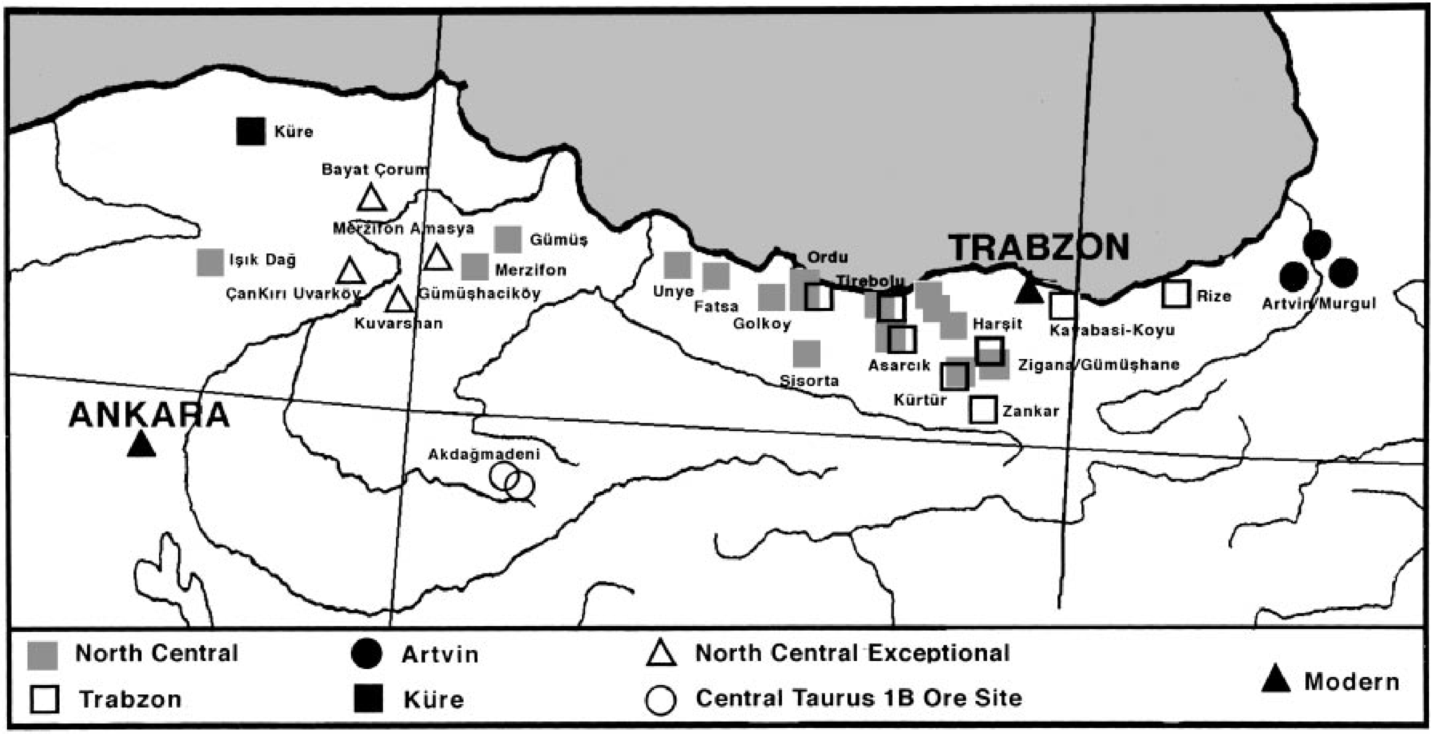

Figure 2 *A map of the source locations for the Black Sea anatolian ore specimens.*

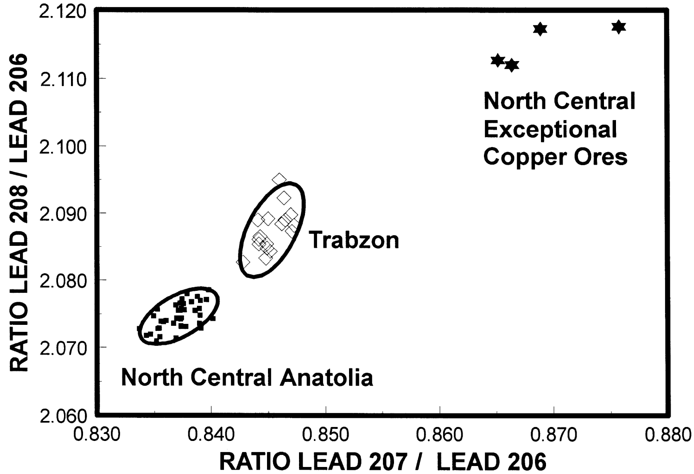

Figure 3 *A stable lead isotope ratio 208/206 versus 207/206 scatter plot for specimens within the North Central Anatolia, the Trabzon and the North Central Exceptional Ore groups.*

two-dimensional projection might fail to reveal all of the separations within the data. Indeed, no matter how well separated any two groups may be in three dimensions, one can always find a two-dimensional projection of them in which they will appear to coincide. In this instance, we have presented both projections, but in following instances of this type we shall, for reasons of economy in publication, present only one of the projections, asking the reader to accept our word that in each instance the second projection would indeed confirm that all of the separations among groups are fully represented in the published projection. The ore source group designated as the North Central Anatolia Group contains specimens from mining sites extending from the Işık Dağ mining region, which is the site located about 90 km due north of Ankara, to mines located just to the west of and inland from Trabzon. The four specimens labelled 'North Central Exceptional Copper Ores' come from the central part of this region. The Trabzon Ore Group

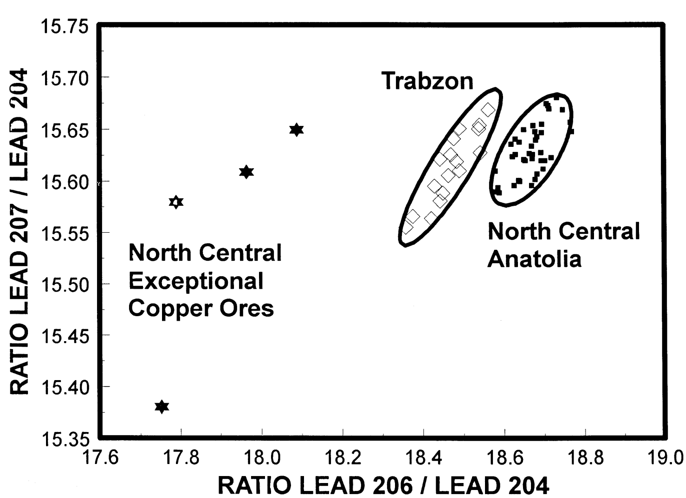

Figure 4 *A stable lead isotope ratio 208/204 versus 207/204 scatter plot for specimens within the North Central Anatolia, the Trabzon and the North Central Exceptional Ore groups.*

contain specimens from mining sites that surround the city of Trabzon to the east, west and south, to a maximum distance of about 175 km. The ore source location map (Fig. 2) shows the ore source sampling areas but not the locations of individual mines. Many of the mining sites that lie immediately west and south of Trabzon have produced specimens of both North Central and Trabzon ore types. The isotopic separation between the two ore groups, however, is so great that one must conclude that at least two quite separate episodes of ore emplacement occurred in this common geographical area.

Our approach has been to seek out such approximately statistically normally distributed clusters of specimens from within reasonably well defined geographical limits, and then to try to evaluate with what statistical probability the isotope ratios of artefacts can be related to them. One cannot be certain, upon the basis of the isotope ratios alone, whether each of the separate specimen isotope ratio groups represent only individual ore deposits, but from the practical point of view we do not see that this degree of geological information is essential. Ours is the pragmatic problem of relating isotope ratio signatures to geographical ore source regions, not that of resolving geological questions of ore deposition within the regions. If, within the same region, two or more deposits have such similar isotope ratios that they cannot be resolved, the best we can do is to treat their combined specimens as a single population. In fact, we have found that the North Central Anatolia Group can be divided into three subgroups that can be just resolved in the three-dimensional isotope ratio space. However, since the three subgroups relate to nearly the same geographical source region, little archaeological advantage would be achieved by relating artefacts to them separately. Conversely, however, if, as is the case with the North Central Anatolia and Trabzon ore specimens, it is obvious from the data that one is dealing with isotopically separate ore deposits, it would be counterproductive to treat them statistically as if they were a single deposit.

The more geographically extended North Central Anatolia Ore Group (which is also the one for which we have found a much larger number of artefacts to have comparable isotope ratios) is presently defined by 21 ore or slag specimens collected by Yener and Özbal and analysed at NIST, 12 specimens collected by the Heidelberg research group and analysed at Mainz, four specimens analyzed by Kouvo and reported in the US Geological Survey Lead Isotope Data Base, and two specimens analysed at Tokyo. The NIST specimens are from mining areas close to the towns of Tirebolu, Giresun, Sebinkarahisar (Sisorta), Ünye (Fatsa), Ordu (Gölköy), Gümüşhane and Merzifon (Gümüşhacıköy) and the mining region of Işık Dağ, due north of Ankara. The lead isotope ratios and specific mine locations for individual specimens are cited in Table 7 of Appendix A. The Mainz specimens are from the vicinity of the towns of Tirebolu, Gümüşhane, Sebinkarahisar, Kürtün, Ordu and Merzifon (Gümüşhacıköy) and the mining sites of Derealan-Bakır-Inkaya and Işık Dağ. The Kouvo specimens are identified as being from Darıdere, Sisorto, Hazine and Haviyana, and the specimens analysed at Tokyo were from Sebinkarahisar (Asarcık) and Tokat (Almus). Descriptions of the individual specimens analysed at NIST, that mostly are as yet unpublished, are given in Appendix A, as well as individual identifications and references for the specimens cited from the published literature. Chemical analyses of the Smithsonian Institution (SI-NIST) ore and slag specimens are given in Table 8 of Appendix A.

The Trabzon ore group is primarily composed of 12 specimens analysed at Mainz. These were matched in their isotope ratios by an ore specimen from the Zigana region analysed by Kouvo, another from the same region analysed at Brookhaven, a slag specimen which was found at Tirebolu and analysed at NIST and two chalcopyrite ore specimens, one from Giresun/Tirebolu–Harköy and one from Trabzon/Maçka, analysed at Tokyo. The Trabzon mining sites to a large degree coincide with the most eastern of the North Central Anatolia sites, except that they include two areas, Kayabaşı Köyü and Rize Madenli/Çateli, which are east of Trabzon. The other locales cited as sources for the specimens analysed at Mainz are Piraziz Maden near Ordu, Lenards Maden, Eseli Madeni, Zankar, Karaerik and Çayırçukur.

ORE AND SLAG SPECIMENS FROM TWO PERIPHERAL SITES

A isotopically distinct group of eight ore and seven slag specimens were taken from four mining sites which are in the vicinity of Artvin, a town located about 150 km east of Trabzon. Fourteen of these specimens, from the Murgul, Gümüşhane, Ilıcaçermik/Kuabukar mine sites, were collected and analysed by the Heidelburg–Mainz group. An additional ore specimen from the mining site of Yukarı Maden Köyü was among those published in 1967 by Brill and Wampler. Figure 5 shows that the isotope ratios of this group lie between the North Central Anatolia and Trabzon fields, overlapping the Trabzon field slightly. However, the geographical location of these mine sites is sufficiently distant from the Trabzon mine sites and the isotope ratios of these specimens sufficiently different from the Trabzon sites to justify considering them separately. They are identified as the Artvin Ore Source Group.

Küre is a mine site located only about 15 km inland from the Black Sea, near the town of Inebolu, and about 300 km west of the coastal mining sites near Ünye and Ordu, where North Central Anatolia and Trabzon ores were obtained. The Heidelberg–Mainz team analysed two ore and two slag specimens from this mining area which had consistent isotope ratios that were significantly different from those of the other Black Sea ores. The Tokyo team found an additional ore specimen from this same area that had matching isotope ratios. Figure 5 also shows how these specimens relate to the other ore source groups. These five matching specimens make it quite definite that a separate ore deposit exists in this region, but they do not constitute a statistically significant sample of the population from which they are derived. However, we have discovered within our database of Anatolian artefacts an isotopically consistent group of 16 artefacts from Kaman-Kalehöyük, Troy and Mersin, to which all of the Küre ore specimens relate with significant probabilities. Because the Küre ore specimens have these significant

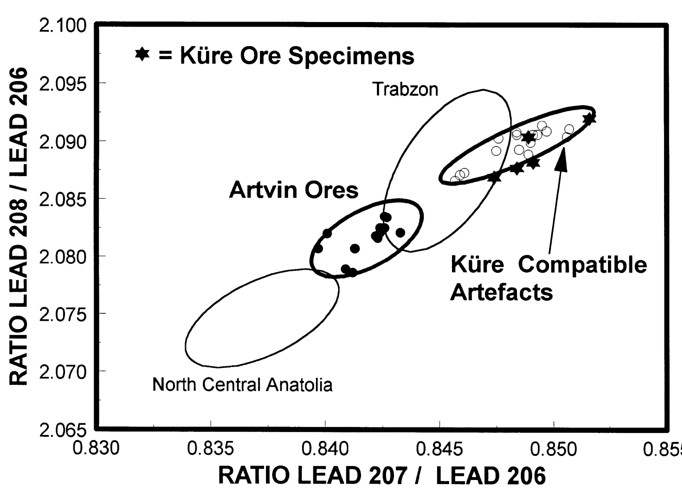

Figure 5 *A stable lead isotope ratio 208/206 versus 207/206 scatter plot for the Artvin Ore, the Küre Ore and the Küre Compatible Artefact specimens. Analogous plots including ratios relative to lead 204 show similar groupings.*

probabilities relative to this artefact group, and because the find sites for the artefacts are both reasonably close to Küre, it would seem very probable that these artefacts were made with Küre metal, and that specimens that statistically relate to the artefact group probably would relate to the Küre Ore Group once it is fully characterized. This artefact group, which we will call the Küre Compatible Artefact Group, is plotted in Figure 5, as are the positions of the Küre ore specimens which relate to it.

OTHER NEAR EASTERN ORE AND ARTEFACT GROUPS THAT HAVE BEEN REASONABLY WELL CHARACTERIZED

There have been 25 other ore sources located in or near to Anatolia, from which a sufficient number of specimens have been analysed for lead isotope ratios to justify their use as population samples for trivariate statistical analysis. These include, from Anatolia, four ore source groups from the Central Taurus, for which data are updated in Appendix B, two from the Troad peninsula (Sayre *et al.* 1992) and one from the Keban mines, which include six specimens analysed at Mainz (Wagner *et al.* 1990; Seeliger *et al.* 1985) and three specimens analysed at NIST (unpublished). From Greece and the Aegean islands there are the Laurion group, two groups from Kythnos and one each from Antiparos, Kea, Poliegos, Seriphos, Siphnos, Syros, Thasos and Thera. Data for all of these groups were recently updated by the Isotrace Laboratory at Oxford, in Stos-Gale *et al.* (1996). However, our Thasos 1 group also includes many other specimens from Thasos analysed at Mainz (Chalkias *et al.* 1988; Vavelidis *et al.* 1985) and isotopically matching ore specimens from the neighbouring mainland Chalcidice peninsula, which were primarily published by Vavelidis. Our present evaluation of our groups on Cyprus is based upon the recent revision and enlargement of these data published by Gale *et al.* (1997). Using these data exclusively, we now feel that the ore specimens from the western Troodos massif, which we had combined into our Cyprus 1 group, can now be meaningfully subdivided into three groups, Cyprus 1A, those from the Limni axis mines, Cyprus 1B, those from the Alestos, Mavrovouni, Meni and Skouriotissa mines of the Solea axis, and Cyprus 1C, specimens from the Apliki mine of the Solea axis (for the locations of these mining locales, see Figure 2 in Stos-Gale *et al.* 1996). Our Cyprus 2 group, which was derived from specimens from mines in the northeastern Troodos, is now closely matched by the combined specimens from the Kambia, Mathiati, Peristerka, Pitharochoma and Troulli mines of the Larnaca axis. We now call this group Cyprus 2A because two new ore groups have now emerged in the new data for this region: Cyprus 2B, specimens from three ore deposits, Agrokipia, Kokkinopezoula and Kokkinoyia, which are closely grouped together in the region west of the Cyprus 2A mines; and Cyprus 2C, the newly analysed specimens from the Sha ore deposit. Previously unpublished data from the Kalavasos axis ore deposits in the southeastern Troodos group well together to form an isotopically quite distinct Cyprus 3 group. Specimens from the Limassol Forest region of the south-east Troodos do not group well together, and we feel that no statistically reliable groups can be derived for these data as they now stand.[1]

In addition to the Küre Compatible Artefact Group, there are two other self-consistent artefact groups, which are likewise reasonably well characterized, that represent ore sources yet to be identified. Together with the Black Sea sources this makes 31 ancient ore sources to which

[1] We will supply, upon request, lists of identifications of specimens we have selected for inclusion in any of the ore source groups described above and identifications of the occasional specimens from the same locations which we consider to differ so significantly in isotope ratios from the group specimens to be excluded as outliers.

artefacts can be compared statistically. This, of course, does not include all of the ancient metal sources in this region, but it does include most of the more likely ones, as these are the sources that have been sought out for analysis. As more lead isotope ratio data are accumulated, some of the already defined source groups are being added to and, hence, are being more fully characterized statistically. This has been particularly true for the four Central Taurus ore groups which we first proposed in 1991 (Yener *et al.* 1991). Since that time Wagner *et al.* (1992) have published lead isotope ratios for four additional Central Taurus ores, Hirao *et al.* (1995) have published 21 such analyses and we have sought out and analysed 11 new Central Taurus ore specimens. The isotope ratios of most of these new ore specimens have fallen well within the original four groups. Hirao *et al.*, in their Figure 6, have shown and commented upon the fact that their values 'coincide very well' with the ones we have published. The two groups that originally were most marginally characterized, Taurus 1B and Taurus 2B, now contain 18 and 14 specimens respectively. We are publishing these combined new analyses in Appendix B, with a note that redefines the expanded Central Taurus ore groups.

With but a few exceptions, such as the Laurion ores in Greece, the isotope fields of these source groups have been found to overlap to some degree. As a rule, however, the overlaps among the isotope ratio fields of these different ore sources are only partial. If one has analysed artefacts derived from two such partially overlapping ore sources, one would expect to encounter some artefacts whose isotope ratios lie in the zone of overlap, with significant statistical probabilities relative to both sources, and others, whose isotope ratios lie outside of the overlap region, with significant probabilities for just one or the other of the ore sources.

ISOTOPIC COMPARISON OF BRONZE AGE ARTEFACTS FROM NEARBY ARCHAEOLOGICAL SITES TO THE MAJOR BLACK SEA ORE SOURCES

Our presently accumulated stable lead isotope ratio database of Bronze Age metal artefacts that have been excavated at Anatolian archaeological sites include measurements on 184 objects that were recovered at nine sites. The sites are situated, at most, a few hundred kilometres from one or more of the four well characterized Black Sea ore sources. These sites, whose locations are shown on the map (Fig. 6), are Alaca, Horoztepe and Mahmatlar in north-central Anatolia, Alişar, Kültepe, Kaman-Kalehöyük, Acemhöyük and Karahöyük in central Anatolia and Beycesultan in southwest Anatolia. Eighty of these artefacts have isotope ratios that significantly overlap only single individual source groups; 47 have isotope ratios with significant probabilities relative to pairs of source groups and 25 have significant probabilities for three or more source groups. Thus more than eight-tenths of the these artefacts have probabilities of relating to one or more of the presently characterized ore sources, of which more than half statistically relate to only single ore sources. As we shall see, in some instances in which artefacts relate to two or more sources, other factors allow one to eliminate one or more of the alternate sources as being unlikely. These 184 artefacts from sites reasonably 'nearby' to the Black Sea ore sources seemed to us to constitute a reasonable group of specimens to serve to evaluate the probabilities with which they individually can be related to Black Sea or other ore sources upon the basis of the isotopic data.

This evaluation was primarily achieved by calculating for each artefact the trivariate probabilities that relate it to each of the Eastern Mediterranean ore sources that are presently acceptably well characterized through lead isotope analysis. Similar probability calculations were made relating each individual artefact to the four isotopically consistent groups of Anatolian artefacts mentioned above. These multivariate probability calculations have an

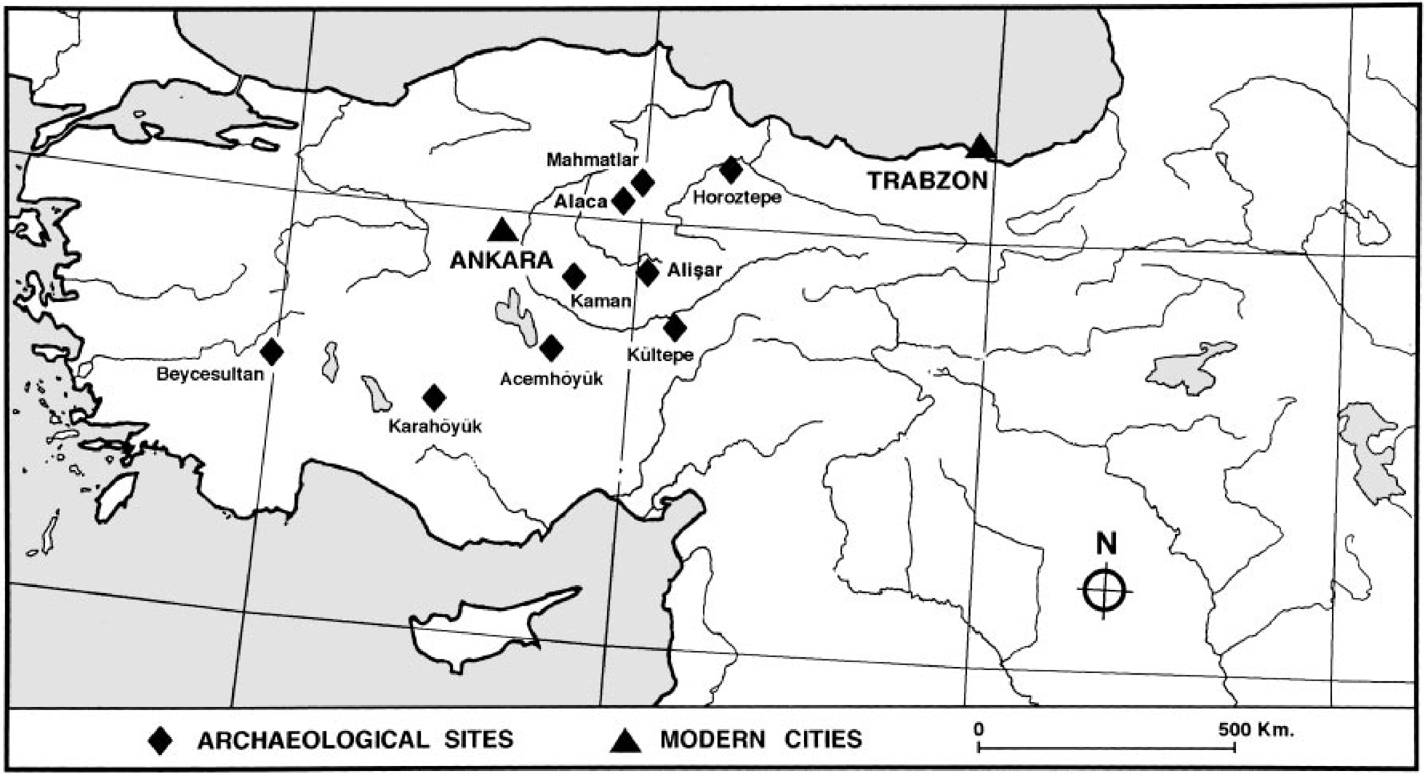

Figure 6 *A map of the archaeological sites within central Anatolia at which the comparison ancient artefact specimens were excavated.*

advantage that they fully take into account the correlations that occur among the variates. For each source group population for which they are calculated, they define ellipsoids, rather than spheres, of equal probabilities that surround the population centroids and whose axes correspond to correlation vectors within the populations. The probabilities calculated are the fraction of the population specimens that lie on or outside of the equal probability ellipses on which the compared specimens lie. It is impossible to find a simple term to define these probabilities. In attempting to do so, we have sometimes called them the probabilities of the individual specimens matching the populations, because they are indeed measures of such matching. However, this, admittedly, is not a precisely correct designation. We will instead simply call them the probabilities for, or relative to, the different ore source groups considered.

The probabilities can be calculated two ways: (1) based upon the assumption that the population sample has a normal distribution, as it presumably would have if the population sample were very large; or (2) based upon assumption of the Hotelling's T^2 distribution for the sample, which takes into account the additional uncertainty that is introduced if the sample has less than an optimum number of specimens. Hotelling's T^2 is the multivariate equivalent of the univariate Student's *t* correction for sample size. The two sets of probabilities are closely related to each other, as the Hotelling's T^2 distribution smoothly converges into the normal distribution as the size of the population sample to which it is applied becomes sufficiently large. Indeed, the two sets of probabilities are calculated with the same computer program, which contains a parameter that defines the population sample size. The actual number of specimens that define a group is entered for this parameter in the Hotelling's T^2 calculations, and an arbitrarily large number—for example, 10 000—is entered for it in the multivariate normal calculations. In ideal statistical analyses one simply increases the population sample size through analyses of additional specimens, until the two sets of probabilities have become nearly identical. In archaeological studies there are seldom enough specimens available for analysis to achieve this ideal condition. However, during the many years in which the statistical methods that we are using here were applied to elemental analysis studies of archaeological materials at Brookhaven National Laboratory, it fairly often happened that groups that initially were defined by quite inadequately small samples were, over time, increased in size through extended collection of specimens and analyses until they were defined by nearly ideally large samples. The way in which the two sets of probabilities related to each other during this process of group size enlargement and the way in which each of them approached the convergent 'ideal' probabilities tended to show consistent patterns. It is upon these practical observations that the following procedures for interpreting these probabilities are based.

The probabilities calculated with Hotelling's T^2 are necessarily larger than those calculated without it, and are almost always larger than those that would be calculated if the population sample size were increased through analysis of additional specimens. Our experience has been that when we have been able to increase the population sample sizes the probabilities calculated without Hotelling's T^2 tend to remain relatively constant, and that those made with Hotelling's T^2 tend to contract to coincide with them. This is what should happen if the original population sample was indeed a reasonably good representative sample of the normally distributed population. This has led us to consider the judgement as to which of the two probabilities is a more reliable measure of the degree to which the specimen matches the group to be moot, and to base our evaluation upon consideration of both probabilities. Accordingly, both calculations are given in the following tables in the form NP/HP, in which NP is the normal distribution based probability and HP the Hotelling's distribution based probability. When an arbitrary level of significance has had to be selected, we have considered the match between a specimen and the group to which it is being compared to be significant when the average of the two probabilities equal or exceeds 5%.

ARTEFACTS THAT RELATE TO THE TRABZUN, ARTVIN AND/OR THE KÜRE COMPATIBLE ARTEFACT SOURCE GROUPS

It is apparent in Figure 5 that the Trabzon isotope field is overlapped in part by both the Artvin and the Küre Compatible Artefact Group fields. However, these three groups, which all have unusually high isotope ratios relative to lead 206, are sufficiently well separated from all of the other well characterized source groups that only one of the artefacts that significantly relate to them has significantly large probabilities relative to any of the other groups. The one exceptional artefact from Beycesultan, AAO020, is shown in Table 1 to have significant probabilities relative to the Trabzon, Artvin and Cyprus 1A ores. Table 1 lists all of the significantly large probabilities for these artefacts, including the probabilities relative to the Cyprus 1 Ore Group but excluding the consistently non-significant probabilities relative to the other 23 ore groups and two artefact groups to which they were compared. This table includes nine artefacts from Kaman-Kalehöyük that have significant probabilities relative only to the Trabzon Group, one from Acemhöyük and one from Kaman-Kalehöyük that relate only to Artvin and four from Kaman-Kalehöyük that relate only to the Küre Compatible Group. These artefacts, we believe, have a high probability of having been derived from the individual sources to which they relate; with the reservation that because the Artvin Group lies totally between the North Central Anatolia and Trabzon groups, any artefact that relates to Artvin could also have been formed out of a mixture of North Central Anatolia and Trabzon metals. There are also listed in Table 1 two artefacts that simultaneously have significant probabilities for both the Trabzon and Küre Compatible Group, and four artefacts with significant probabilities for both the Trabzon and the Artvin Group, of which one has an additional probability of matching Cyprus 1A. Lead isotope ratios, therefore, fail to indicate a single probable source for these six artefacts but do identify them as likely to have been derived from Black Sea region ores.

Table 1 also lists the probabilities with which the actual Küre ore specimens relate to the groups, showing the degree to which they are significantly related to the Küre Compatible Artefact Group. It should be noted that we have found a number of other artefacts from other parts of Anatolia and from other time periods than those we have selected for this study that conform to and have been included in the Küre Compatible Artefact group. It should also be noted that the Trabzon and Artvin ore source groups both have isotope ratios similar to some copper ore specimens from Crete that were analysed at Oxford (Gale and Stos-Gale 1985, 1986). We feel, however, that the present assemblage of ore data from Crete is not internally consistent enough to be from a single source, and no one group of isotopically consistent specimens within it is large enough to be treated statistically as a 'reasonably well characterized' ore source. We will note only that there is this isotopic similarity between these Eastern Anatolian Black Sea sources and Crete and, therefore, it is possible, although for geographical reasons unlikely, that some of the artefacts that statistically relate to the Black Sea sources might have come from Crete.

ARTEFACTS THAT RELATE TO THE NORTH CENTRAL ANATOLIA ORE SOURCE

Seventy-six of the Central Anatolian artefacts show significant probabilities relative to the North Central Anatolia ore field. The North Central Anatolia differ from the other Black Sea sources,

Table 1 *Artefacts from nearby Anatolian sites with significant probabilities for the Trabzon ore, Artvin ore or the Küre Compatible Artefact source groups and the Küre ore specimens*

CAL ID	*Data source*		*Probabilities relative to specimen group*							
	*Ref.**	*ID*	*Trabzon ore*		*Artvin ore*		*Küre artefact*		*Cyprus 1A ore*	
			Normal†	*Log-normal‡*	*Normal*	*Log-normal*	*Normal*	*Log-normal*	*Normal*	*Log-normal*
Artefacts with predominant probabilities for Trabzon										
AAJ9001	2	A 1	**34.8/44.1**	[**34.8/44.2**]	0.1/1.5	[0.1/1.5]	**8.8/29.4**	[**18.8/28.3**]	0.0/0.0	[0.0/0.0]
AAJ9002	2	A 2	**29.7/39.2**	[**29.5/39.1**]	0.8/**5.3**	[0.8/**5.3**]	0.2/2.4	[0.2/2.4]	0.0/0.0	[0.0/0.0]
AAJ9009	2	A 9	**15.4/25.0**	[**15.4/25.1**]	0.0/0.1	[0.0/0.1]	0.5/3.8	[0.5/3.7]	0.0/0.0	[0.0/0.0]
AAJ9013	2	A 13	**10.7/19.9**	[**10.7/19.9**]	0.5/4.0	[0.5/4/0]	0.0/0.1	[0.0/0.0]	0.0/0.1	[0.0/0.1]
AAJ9221	3	9 221	**22.3/32.2**	[**22.2/32.0**]	0.4/3.7	[0.4/3.7]	0.1/1.4	[0.1/1.4]	0.0/0.3	[0.0/0.2]
AAJ9222	3	9 222	**18.0/27.8**	[**17.9/27.7**]	1.1/**6.1**	[1.1/**6.1**]	0.0/1.0	[0.0/1.0]	0.6/1.7	[0.4/1.3]
AAJ9235	3	9 235	**10.1/19.2**	[**0.2/19.3**]	0.0/0.0	[0.0/0.0]	0.1/1.7	[0.1/1.7]	0.0/0.0	[0.0/0.0]
AAJ8901	1	8 901	**8.5/17.3**	[**8.5/17.2**]	1.2/**6.7**	[1.2/**6.6**]	0.0/0.5	[0.0/0.5]	0.0/0.0	[0.0/0.0]
AAJ9244	3	9 244	3.0/**9.4**	[3.0/**9.3**]	0.0/1.0	[0.0/1.0]	0.0/0.6	[0.0/0.6]	0.0/0.0	[0.0/0.0]
AAJ9219	3	9 219	2.6/**8.5**	[2.5/**8.5**]	0.0/0.6	[0.0/0.6]	0.0/0.5	[0.0/0.5]	0.0/0.1	[0.0/0.0]
Artefacts with predominant probabilities for Artvin										
AAJ8912	1	8 912	**14.6/24.2**	[**14.5/24.2**]	**43.0/52.2**	[**43.1/52.2**]	0.0/0.5	[0.0/0.5]	0.1/0.4	[0.1/0.3]
AAJ9113	3	9 113	1.5/**6.4**	[1.5/**6.3**]	**79.5/82.8**	[**79.5/82.8**]	0.0/0.4	[0.0/0.4]	0.0/0.0	[0.0/0.0]
AAJ9218	3	9 218	**18.5/28.4**	[**18.4/28.3**]	**41.8/51.0**	[**41.8/51.0**]	0.0/0.8	[0.0/0.8]	0.0/0.2	[0.0/0.1]
AAO020	5	11 745	**5.9/13.9**	[**5.9/13.8**]	**12.6/23.5**	[**12.8/23.7**]	0.0/0.2	[0.0/0.2]	**8.5/12.6**	[**7.3/11.0**]
AAN841	NIST data		2.5/**8.4**	[2.4/**8.3**]	4.2/**12.5**	[4.1/**12.4**]	0.0/0.6	[0.0/0.6]	0.0/0.0	[0.0/0.0]
AAN843	NIST data		0.0/0.3	[0.0/0.3]	**21.0/32.3**	[**21.0/32.3**]	0.0/0.1	[0.0/0.1]	0.0/0.0	[0.0/0.0]
Artefacts with predominant probabilities for Küre Compatible Artefact Group										
AAJ8915	1	8 915	**34.0/43.5**	[**34.1/43.6**]	0.0/0.0	[0.0/0.0]	**41.6/50.2**	[**41.6/50.1**]	0.0/0.0	[0.0/0.0]
AAJ9030	2	A 30	0.1/1.4	[0.1/1.4]	0.0/0.0	[0.0/0.0]	**93.8/94.6**	[**93.8/94.6**]	0.0/0.0	[0.0/0.0]
AAJ9033	2	A 33	0.2/2.3	[0.2/2.4]	0.0/0.0	[0.0/0.0]	**38.5/47.9**	[**38.5/47.9**]	0.0/0.0	[0.0/0.0]
AAJ9034	2	A 34	0.1/1.6	[0.1/1.6]	0.0/0.0	[0.0/0.0]	**87.6/89.4**	[**87.6/89.4**]	0.0/0.0	[0.0/0.0]
AAJ9035	2	A 35	0.4/2.9	[0.4/3.0]	0.0/0.0	[0.0/0.0]	**76.5/80.1**	[**76.6/80.2**]	0.0/0.0	[0.0/0.0]
The Küre ore specimens										
AOJ034	4	34	0.1/1.2	[0.1/1.3]	0.0/0.0	[0.0/0.1]	**91.9/93.9**	[**91.9/93.1**]	0.0/0.0	[0.0/0.0]
AOM162A	6	TG162A-1	0.0/0.4	[0.0/0.4]	0.0/0.1	[0.0/0.2]	4.9/**12.9**	[4.8/**12.9**]	0.0/0.0	[0.0/0.0]
AOM162B	6	TG162B-1.1	0.0/0.1	[0.0/0.1]	0.0/0.0	[0.0/0.0]	**5.8/14.3**	[**6.0/14.5**]	0.0/0.0	[0.0/0.0]
AOM162C	6	TG162C-2	0.0/0.1	[0.0/0.1]	0.0/0.1	[0.0/0.1]	2.6/**9.0**	[2.5/**9.0**]	0.0/0.0	[0.0/0.0]
ASM162E	6	TG162E	1.9/**7.1**	[1.9/**7.2**]	0.0/0.0	[0.0/0.2]	**8.4/17.7**	[**8.3/17.6**]	0.0/0.0	[0.0/0.0]

* References: 1, Hirao *et al.* (1992); 2, Hirao and Enomoto (1993); 3, Hirao and Enomoto (1994); 4, Hirao *et al.* (1995); 5, Gale, Stos-Gale and Gilmore (1985); 6, Seelinger *et al.* (1985).

† Probabilities calculated assuming the data conform to trivariate Normal or Hotelling's T^2 distributions.

‡ Probabilities calculated assuming the logarithms of the data conform to trivariate Normal or Hotelling's T^2 distributions.

however, in that it, at least peripherally, overlaps with nine other Near Eastern ore sources. Therefore, the degree to which these artefacts can be related uniquely or quasi-uniquely to the North Central Anatolia ores upon the basis of their isotope ratios is a moot and significant question. Table 2 lists the trivariate probabilities relative to all ten on these potentially competing ore sources for 34 artefacts which have significant probabilities only relative to the North Central source. At this stage of the development of a lead isotope database for the Near East, we do not claim that probabilities that relate artefacts uniquely to one metal source prove that the artefacts were derived for that source, but we do believe they indicate a strong likelihood that they were. Certainly, the nine artefacts in Table 1 which have unique probabilities for

Table 2 *Artefacts from nearby Anatolian sites with significant probabilities only for the North Central Anatolia ore source*

SI ID	*Data source*		*Probabilities for ore source group*									
	*Ref.**	*ID*	*N. Central*	*Thasos 1*	*Troad 1*	*Troad 2*	*Cyprus 2A*	*Taurus 1B*	*Taurus 2A*	*Siphnos*	*Kythnos 1*	*Syros*
AAJ8804	1	8 804	4.2/**6.8**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.4	0.0/0.0	0.0/0.0	0.0/0.0
AAJ8808	1	8 808	**5.9/8.8**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.2	0.0/0.0	0.0/0.0	0.0/0.0
AAJ8902	1	8 902	**5.2/8.0**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ8904	1	8 904	**45.3/48.6**	0.0/0.0	0.0/0.0	0.0/0.1	0.0/0.0	0.0/0.0	0.0/0.0	0.4/2.1	0.0/0.0	0.0/0.0
AAJ8909	1	8 909	**89.0/89.7**	0.0/0.0	0.0/0.9	0.0/0.4	0.3/0.9	0.0/0.2	0.0/0.0	0.0/0.3	0.0/1.5	0.0/0.0
AAJ9006	2	A 6	**82.6/83.6**	0.0/0.0	0.0/0.1	0.0/0.2	0.1/0.3	0.0/0.1	0.0/0.0	0.1/1.1	0.0/0.4	0.0/0.0
AAJ9010	2	A 10	**94.9/95.2**	0.0/0.0	0.0/0.1	0.0/0.2	0.8/1.8	0.0/0.0	0.0/0.0	0.1/0.9	0.0/0.4	0.0/0.0
AAJ9014	2	A 14	**75.8/77.3**	0.0/0.0	0.1/2.4	0.0/0.5	0.4/0.9	0.0/0.6	0.0/0.1	0.0/0.5	0.0/0.8	0.0/0.0
AAJ9015	2	A 15	**8.6/12.0**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.1	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9016	2	A 16	**10.6/14.2**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9025	2	A 25	**31.9/35.8**	0.0/0.0	0.0/0.0	0.0/0.0	0.4/1.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9029	2	A 29	**11.5/15.2**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	1.2/4.5	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9102	3	9 102	**8.5/11.9**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.3/1.9	0.5/2.5	0.0/0.0	0.0/0.0
AAJ9114	3	9 114	**57.0/59.7**	0.0/0.0	0.8/**5.8**	0.0/1.1	1.3/2.6	0.0/0.7	0.0/0.1	0.0/0.1	0.0/0.9	0.0/0.0
AAJ9118	3	9 118	**68.3/70.3**	0.0/0.0	0.1/2.6	0.0/0.8	2.3/4.1	0.0/0.3	0.0/0.1	0.0/0.2	0.0/0.7	0.0\0.0
AAJ9202	3	9 202	**81.6/82.7**	0.0/0.0	0.6/4.9	0.0/0.7	1.4/2.7	0.0/0.5	0.0/0.0	0.0/0.1	0.3/3.7	0.0/0.0
AAJ9205	3	9 205	**91.9/92.2**	0.0/0.0	0.0/0.1	0.0/0.2	0.3/0.9	0.0/0.1	0.0/0.0	0.1/0.9	0.0/0.4	0.0/0.0
AAJ9206	3	9 206	**13.4/17.3**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.1/1.2	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9207	3	9 207	**25.5/29.6**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.1	0.0/0.0	0.0/0.0	0.0/0.1	0.0/0.0	0.0/0.0
AAJ9211	3	9 211	**89.2/89.8**	0.0/0.0	0.0/1.1	0.0/0.3	0.5/1.3	0.0/0.2	0.0/0.0	0.0/0.1	0.1/2.5	0.0/0.0
AAJ9229	3	9 229	**59.5/62.1**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.1	0.0/0.0	0.3/2.0	0.1/1.1	0.0/0.0	0.0/0.0
AAJ9234	3	9 234	**29.5/33.5**	0.0/0.0	0.1/1.7	0.0/0.3	0.0/0.1	0.2/2.0	0.1/0.7	0.5/2.6	0.0/0.1	0.0/0.0
AAJ9245	3	9 245	**87.1/87.8**	0.0/0.0	0.1/2.5	0.0/0.5	2.0/3.6	0.0/0.2	0.0/0.0	0.0/0.0	0.3/3.9	0.0/0.0
AAN924	NIST data		**50.4/53.5**	0.0/0.0	0.5/4.5	0.0/0.1	0.0/0.1	0.1/1.3	0.0/0.0	0.0/0.0	0.0/0.4	0.0/0.0
AAN926	NIST data		**57.2/59.9**	0.0/0.0	0.7/**5.5**	0.0/0.1	0.0/0.2	0.1/1.1	0.0/0.0	0.0/0.0	0.0/0.7	0.0/0.0
AAN2032	NIST data		**81.3/82.4**	0.0/0.0	0.1/1.8	0.0/0.3	2.3/4.0	0.0/0.1	0.0/0.0	0.0/0.0	0.1/2.6	0.0/0.0
AAN17 095	NIST data		4.5/**7.2**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	1.6/**5.2**	0.0/0.0	0.0/0.0	0.0/0.0
AAN17 096	NIST data		**68.4/70.4**	0.0/0.0	0.1/1.7	0.0/0.4	0.0/0.2	0.0/0.7	0.0/0.1	0.1/0.9	0.0/0.8	0.0/0.0
AAN007	NIST data		**15.5/19.5**	3.4/6.1	0.1/2.3	0.0/0.2	0.2/0.7	0.6/3.6	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAO005	4	11 790	**8.1/11.5**	0.0/0.0	0.0/0.2	0.0/0.0	0.0/0.0	0.0/0.6	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAO008	4	11 789	**6.3/9.4**	0.0/0.0	0.0/0.4	0.0/1.8	1.4/2.7	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.6	0.0/0.0
AAO012	4	11 758	**66.1/68.2**	0.0/0.0	0.0/0.0	0.0/0.0	0.9/1.9	0.0/0.0	0.0/0.2	0.0/0.0	0.0/0.0	0.0/0.0
AAO015	4	11 782	**7.8/11.1**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.9/3.6	0.0/0.2	0.0/0.0	0.0/0.0
AAO018	4	11 759	**9.1/12.6**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.3	0.1/1.1	0.0/0.0	0.0/0.0

* References: 1, Hirao *et al.* 1992; 2, Hirao and Enomoto (1993); 3, Hirao and Enomoto (1994); 4, Gale, Stos-Gale and Gilmore (1985).

Table 3 *Artefacts from nearby Anatolian sites with significant probabilities or the North-Central and one other ore source*

SI ID	*Data source*		*Probabilities for ore source group*									
	Ref.	*ID*	*N. Central*	*Thasos 1*	*Troad 1*	*Troad 2*	*Cyprus 2A*	*Taurus 1B*	*Taurus 2A*	*Siphnos*	*Kythnos*	*1 Syros*
AAJ9008	2	A 8	**65.4/67.6**	0.0/0.0	4.8/**14.4**	0.0/1.2	2.5/4.3	0.0/0.8	0.0/0.0	0.0/0.0	1.2/**7.1**	0.0/0.0
AAJ8813	1	8 813	**75.6/77.1**	0.0/0.0	0.0/0.0	0.0/0.4	**11.9/15.3**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/1.2	0.0/0.0
AAJ8814	1	8 814	**76.0/77.5**	0.0/0.0	0.0/0.0	0.0/0.8	**21.3/25.0**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/1.5	0.0/0.0
AAJ8903	1	8 903	**63.2/65.5**	0.0/0.0	0.0/0.3	0.0/0.7	**34.7/38.2**	0.0/0.0	0.0/0.0	0.0/0.1	0.0/0.9	0.0/0.0
AAJ9020	2	A 20	**77.5/78.8**	0.0/0.0	0.0/0.0	0.0/0.1	**58.4/60.7**	0.0/0.0	0.0/0.1	0.2/1.3	0.0/0.0	0.0/0.0
AAJ9103	3	9 103	**37.5/41.6**	0.0/0.0	0.0/0.0	0.0/0.0	**6.2/9.0**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9220	3	9 220	**84.8/85.7**	0.0/0.0	0.0/0.0	0.0/0.0	**11.2/14.5**	0.0/0.0	0.0/0.0	0.7/3.2	0.0/0.0	0.0/0.0
AAJ9226	3	9 226	**15.1/19.0**	0.0/0.0	0.0/0.0	0.0/0.1	**10.8/14.1**	0.0/0.0	0.0/0.0	0.0/0.2	0.0/0.0	0.0/0.0
AAO010	4	11 787	**91.4/91.8**	0.0/0.0	0.0/0.1	0.0/0.4	**28.8/32.5**	0.0/0.0	0.0/0.0	0.0/0.3	0.0/0.4	0.0/0.0
AAO011	4	11 757	**86.4/87.2**	0.0/0.0	0.0/1.3	0.0/0.4	**9.5/12.7**	0.0/0.3	0.0/0.1	0.0/0.4	0.0/1.2	0.0/0.0
AAO014	4	11 755	**29.7/33.8**	0.0/0.0	0.3/3.8	0.0/1.4	**9.5/12.7**	0.0/0.0	0.0/0.0	0.0/0.0	0.2/3.2	0.0/0.0
AAO017	4	11 752	**57.8/60.5**	0.0/0.0	0.0/0.8	0.0/0.7	**22.6/26.3**	0.0/0.0	0.0/0.0	0.0/0.0	0.1/1.6	0.0/0.0
ASJ035	4	35	**50.5/53.6**	0.0/0.0	1.0/**6.5**	0.0/0.5	**5.8/8.5**	0.0/0.1	0.0/0.0	0.0/0.0	0.2/3.0	0.0/0.0
AAN008	NIST data		**8.7/12.2**	0.0/0.0	0.0/0.2	0.0/0.0	0.0/0.0	**25.7/34.9**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.4
AAN927	NIST data		**6.3/9.3**	0.0/0.0	1.0/**6.4**	0.0/0.1	0.0/0.0	**57.1/63.1**	0.0/0.0	0.0/0.0	1.2/**7.2**	1.7/**5.1**
AAJ8818	1	8 818	**14.2/18.1**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**21.7/29.5**	0.0/0.0	0.0/0.0	0.0/0.0
AAJ8922	1	8 922	**8.9/12.2**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**22.6/30.5**	0.0/0.0	0.0/0.0	0.0/0.0
AAJ8924	1	8 924	**10.7/14.4**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	3.8/**9.0**	0.0/0.1	0.0/0.0	0.0/0.0
AAJ8932	1	8 932	**8.7/12.2**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**13.2/20.7**	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9228	3	9 238	**15.3/19.3**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.1	**5.1/11.0**	0.5/2.5	0.0/0.0	0.0/0.0
AAJ8812	1	8 812	**20.2/24.2**	0.0/0.0	0.0/0.1	0.0/0.1	0.0/0.0	0.0/0.1	0.0/0.1	**5.7/11.8**	0.0/0.1	0.0/0.0
AAJ8914	1	8 914	**19.9/24.0**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.4/2.1	**40.7/47.2**	0.0/0.0	0.0/0.0
AAJ9031	2	A 31	4.2/**6.8**	0.0/0.0	0.0/0.1	0.0/0.1	0.0/0.0	0.0/0.0	0.0/0.2	**19.5/27.4**	0.0/0.1	0.0/0.0
AAJ9112	3	9 112	**83.9/84.9**	0.0/0.0	0.0/0.0	0.0/0.1	0.1/0.4	0.0/0.0	0.1/0.9	**14.6/22.2**	0.0/0.0	0.0/0.0
AAJ9213	3	9 213	**6.0/9.0**	0.0/0.0	0.1/2.5	0.0/0.2	0.0/0.0	0.0/1.2	0.0/0.4	2.9/**7.6**	0.0/0.1	0.0/0.0
AAN842	NIST data		**40.5/43.9**	0.0/0.0	0.0/0.1	0.0/0.1	0.0/0.0	0.0/0.1	0.0/0.3	**19.3/27.2**	0.0/0.1	0.0/0.0

* References: 1, Hirao *et al.* (1992); 2, Hirao and Enomoto (1993); 3, Hirao and Enomoto (1994); 4, Gale, Stos-Gale and Gilmore (1985).

Trabzon, together with the 34 artefacts in Table 2 with unique probabilities for North Central Anatolia, provide very convincing evidence that the Trabzon and more western coastal mines were a major source of metal for the central Anatolian region during the second and first millennia BC.

Table 3 lists an additional 25 artefacts that match North Central Anatolia and only one other ore source group. Other considerations often will determine the actual significance that one gives to these probabilities relative to other source groups. For example, considering the artefacts that show significant probabilities for both North Central and Siphnos, the distance of Siphnos from the artefact find sites and its insular nature together would make it a much less likely source for these artefacts. Additional evidence that North Central is a more probable source for these artefacts than Siphnos lies in the distribution of their isotope ratios in scatter plots. In Figure 7, all of the artefacts that have significant probabilities relative to Siphnos lie within or very close to the region of isotope ratio overlap with North Central. This is true in all three dimensions and, in fact, no artefacts were encountered with significant probabilities relative to Siphnos that did not also have significant probabilities relative to North Central Anatolia. If the artefacts were truly derived from Siphnos ores, one would expect that they would fill the Siphnos ore isotope field much more evenly and fully. These considerations do not furnish absolute proof that none of the artefacts with significant probabilities relative to Siphnos could have come from Siphnos, but they do indicate that it is definitely more likely that they were derived from the North Central ores. Figure 7 also shows that all of the artefacts with significant probabilities relative to the Cyprus 2A ores lie within the North Central field, and Table 3 shows that all of these artefacts have significantly lower probabilities relative to Cyprus 2A than to the North Central group. These considerations lead us to believe that these artefacts are also more likely to have been derived from North Central ores.

Table 4 lists 17 artefacts for which lead isotope ratios give much more ambiguous indications of origin, in that they not only have significant probabilities relative to the North Central Anatolia source but have significant probabilities relative to two or more other ore sources. We

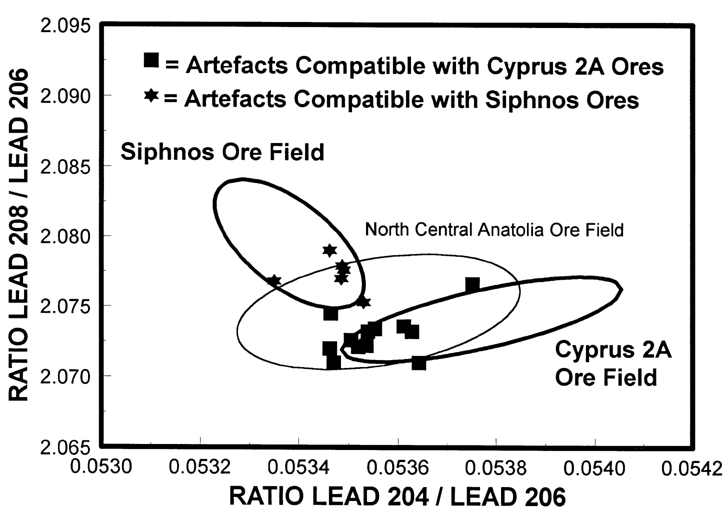

Figure 7 *A stable lead isotope ratio 208/206 versus 204/206 scatter plot comparison among artefact specimens that are jointly compatible with the Central Anatolia ore field and either the Siphnos or the Cyprus 2A ore field. Analogous plots including ratios relative to lead 207 show similar groupings.*

Table 4 *Artefacts from nearby Anatolian sites with significant probabilities for the North Central Anatolia and two or more other ore sources*

CAL ID	*Data source*		*Probabilities for ore source group*									
	Ref.	*ID*	*N. Central*	*Thasos 1*	*Troad 1*	*Troad 2*	*Cyprus 2A*	*Taurus 1B*	*Taurus 2A*	*Siphnos*	*Kythnos 1*	*Syros*
Two other ore sources												
AAB1330	NIST data		**41.7/45.0**	0.0/0.0	**18.7/30.9**	0.0/2.2	2.5/4.4	0.1/1.1	0.0/0.0	0.0/0.0	4.1/**13.2**	0.0/0.1
AAJ9019	2	A 19	**18.1/22.2**	0.0/0.2	**25.1/37.2**	0.1/4.1	1.1/2.2	0.3/2.3	0.0/0.0	0.0/0.0	**14.5/26.4**	0.1/0.6
AAJ9021	2	A 21	**73.8/75.4**	0.0/0.0	**5.2/15.0**	0.0/0.5	0.6/1.4	0.1/1.3	0.0/0.0	0.0/0.0	2.2/**9.6**	0.0/0.0
AAJ9022	2	A22	**62.6/65.0**	0.0/0.0	**8.6/19.7**	0.0/0.4	0.1/0.2	0.4/2.9	0.0/0.0	0.0/0.0	2.2/**9.6**	0.0/0.0
AAJ9111	3	9 111	**24.3/28.4**	0.0/0.0	**31.4/43.1**	0.0/3.5	1.1/2.2	0.3/2.6	0.0/0.0	0.0/0.0	**6.4/16.7**	0.0/0.3
AAJ9116	3	9 116	**10.6/14.2**	1.0/2.4	**11.1/22.7**	0.0/3.7	0.6/1.5	0.6/0.3	0.0/0.0	0.0/0.0	**41.8/51.8**	0.2/1.5
AAJ9214	3	9 214	3.7/**6.2**	0.0/0.1	**56.2/64.1**	0.0/1.0	0.0/0.0	**65.4/70.2**	0.0/0.1	0.0/0.0	0.1/2.5	0.0/0.1
AAJ9247	3	9 247	**34.2/38.1**	0.0/0.8	**21.2/33.4**	0.0/0.9	0.0/0.2	2.9/**8.7**	0.0/0.1	0.0/0.1	0.1/1.9	0.0/0.0
AAO003	4	11 768	**5.9/8.9**	0.1/0.5	1.2/**7.2**	1.3/**11.9**	1.0/2.1	0.0/0.1	0.0/0.0	0.0/0.0	2.7/**10.7**	0.0/0.2
AAO007	4	11 788	3.8/**6.3**	3.4/6.1	2.2/**9.6**	1.5/**12.4**	0.2/0.7	0.0/1.5	0.0/0.1	0.0/0.0	0.0/4.7	0.0/0.0
Three other ore sources												
AAJ8921	1	8 921	4.9/**7.7**	**12.3/16.4**	2.6/**10.5**	0.6/**8.7**	0.5/1.1	0.1/1.4	0.0/0.0	0.0/0.0	**30.5/42.2**	0.0/0.3
AAJ8906	1	8 906	**14.7/18.1**	0.2/0.8	**18.4/30.6**	0.0/1.7	0.5/1.2	2.8/**8.5**	0.0/0.0	0.0/0.0	**50.4/59.3**	1.1/3.8
AAJ9204	3	9 204	**9.8/13.3**	0.1/0.3	**63.0/69.7**	0.0/0.9	0.0/0.1	**79.7/82.4**	0.0/0.0	0.0/0.0	**29.4/41.2**	0.2/1.2
AAJ9215	3	9 215	**37.7/41.8**	0.0/0.0	**69.4/74.8**	0.0/1.1	0.1/0.5	4.6/**11.4**	0.0/0.0	0.0/0.0	**6.7/17.1**	0.0/0.1
Four other ore sources												
AAJ8821	1	8 821	**5.8/8.8**	**11.1/15.2**	3.1/**11.5**	0.0/1.1	0.1/0.2	**43.4/50.9**	0.0/0.0	0.0/0.0	**90.1/91.7**	1.6/4.7
AAJ9124	3	9 124	**6.3/9.3**	**5.8/9.1**	**9.6/20.8**	0.0/1.7	0.0/0.2	**46.5/53.7**	0.0/0.0	0.0/0.0	**70.7/75.9**	0.3/1.8
AAJ9012	2	A 12	**14.2/18.1**	0.2/0.6	3.7/**12.5**	0.0/0.3	0.1/0.4	**21.1/30.4**	0.0/0.0	0.0/0.0	**14.0/25.9**	**15.7/22.7**

* References: 1, Hirao *et al.* (1992); 2, Hirao and Enomoto (1993); 3, Hirao and Enomoto (1994); 4, Gale, Stos-Gale and Gilmore (1985).

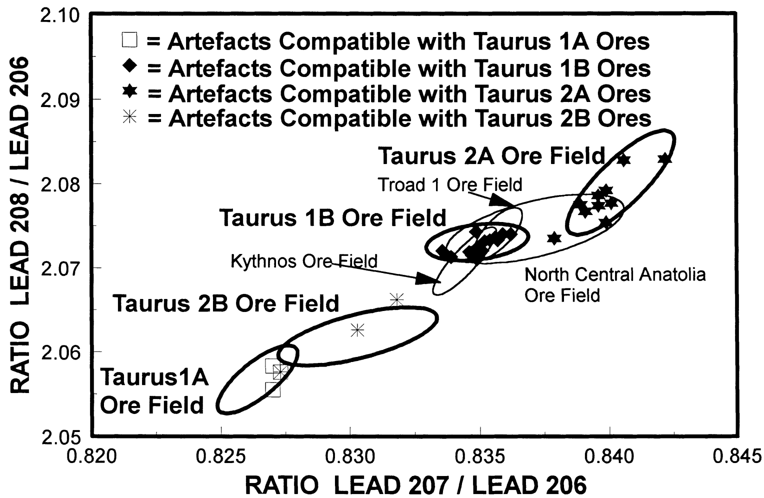

Figure 8 *A stable lead isotope ratio 208/206 versus 207/206 scatter plot relating artefacts compatible with the Taurus ore fields to the North Central Anatolia and other ore fields. Analogous plots including ratios relative to lead 204 show similar groupings.*

do not want to gloss over this problem of multiple overlap among ore source groups but, rather, to attempt to evaluate how serious a problem it is. It is interesting to note how similar the probability patterns for all of the specimens listed in Table 4 are. All of them, of course, have significant probabilities relate to North Central, but all of them also have significant probabilities relative to either Troad 1 or Troad 2, and the mines of the Troad region are nearly as accessible a source for metal for the Central Anatolian archaeological sites in question as the North Central Anatolia mines. Also, all but three have significant probabilities for Kythnos 1, and about half have significant probabilities relative to Taurus 1B. There is a region, therefore, in lead isotope ratio space in which the North Central, Troad 1, Kythnos 1 and Taurus 1B fields all badly overlap, and all of the specimens listed in Table 4 appear to have isotope ratios that place them within or adjacent to this region. The overlap of these four source fields is shown in Figure 8, where it is obvious that, although a substantial portion of the North Central Anatolia field lies outside of the overlap region, most of the other three fields are badly overlapped. It will seldom be possible to relate artefacts that do contain Troad 1, Taurus 1B or Kythnos 1 metals to these sources through lead isotope measurements alone. One might hope that stylistic or archaeological considerations, or analysis of the chemical compositions of the artefacts, might provide bases for further discrimination among these potential sources.

ARTEFACTS THAT MIGHT CONTAIN BOTH NORTH CENTRAL AND TRABZON METALS

Because of the likelihood that the North Central and Trabzon ores were being mined in the same region at the same time, there is an unusually high probability that the two metals might have been mixed in the fabrication of artefacts. The isotope ratios of artefacts that were formed by mixing North Central and Trabzon metals should logically lie in the volume of isotope ratio space that lies intermediate between the North Central and Trabzon isotope fields. We have, therefore, sought out all of the Central Anatolian artefacts with ratios that lie in this space and have plotted their positions in Figure 9. The positions of all of the artefacts that have significant

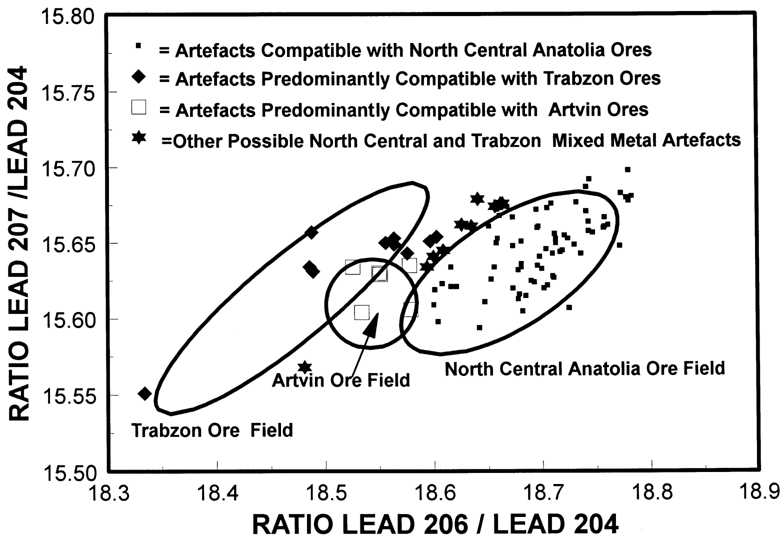

Figure 9 *A stable lead isotope ratio 207/204 versus 206/204 scatter plot showing how artefacts relate to the North Central Anatolia, the Trabzon and the Artvin ore fields. Analogous plots including ratios relative to lead 207 show similar groupings.*

probabilities for the North Central, Trabzon and Artvin ore fields have been plotted to show how fully they cover these fields. Eleven artefacts that do not otherwise relate to any of the established source groups were found to lie in this region and are plotted with stars. They all clearly could have been made of mixed North Central and Trabzon metals, as could all of the specimens that match the Artvin field.

The degree to which all of the three source fields plotted are reasonably well covered with isotopically related artefacts again provides a measure of how likely these fields are as sources for the artefacts. In all, 83 of the artefacts plotted in Tables 11 and 12 of Appendix B are either isotopically compatible with the North Central or Trabzon fields or lie intermediate between then. Certainly not all of these artefacts were derived from Black Sea Coast ores, but it is highly probable that a large fraction of them were. Certainly the Central Black Sea Coast mines must have been the major source of metal for these artefacts.

ARTEFACTS THAT RELATE ONLY TO OTHER ORE SOURCES

Among the specimens that do not match any of the Black Sea sources, we have encountered 18 artefacts that match only single ore sources, six artefacts that match two ore source and six that match three or more sources (see Table 5). While the probabilities that uniquely relate the 18 specimens to individual ore sources do not provide absolute proof that the artefacts were derived from the sources to which they relate, they certainly establish that it is relatively likely that they were. Inference of this type should, of course, be tempered by the numbers themselves. For example, the probabilities that relate the specimen AAJ8815 to Laurion are just minimally significant, while those relating AAJ9115 to Laurion are definitely significant.

Hirao, Enomoto and Tachikawa (1995) concluded that many of the artefacts from levels II and III at Kaman-Kalehöyük (20th to 4th centuries BC) were fabricated of metals derived from the Central Taurus mines. There is much evidence in Table 4 to confirm this conclusion. Table 5 lists

Table 5 *Artefacts from nearby Anatolian sites with significant probabilities for only the more distant ore sources*

CAL ID	*Data source*		*Probabilities for ore source group*											
	*Ref.**	*ID*	*Thasos 1*	*Cyprus 2C*	*Laurion*	*Kythnos 1*	*Taurus 1A*	*Taurus 1B*	*Taurus 2A*	*Taurus 2B*	*Troad 1*	*Troad 2*	*Thera*	*Seriphos*
Compatible with one ore source														
AAO021	4	11 774	0.0/0.0	**5.8/15.9**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.1	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ8815	1	8 815	0.0/0.0	0.0/0.0	3.7/**6.4**	0.0/0.1	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.3	0.0/0.0	0.0/0.0
AAJ9115	3	9 115	0.0/0.0	0.0/0.0	**10.5/14.4**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	1.4/**7.0**	0.0/0.0	0.0/1.8	0.0/0.0	0.0/0.0
AAJ9242	3	9 242	0.0/0.0	0.0/0.0	0.5/1.4	**7.8/18.6**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/1.3	0.0/0.0	0.1/3.9	0.0/0.0	0.0/0.0
AAO022	4	11 778	0.0/0.1	0.0/0.0	0.0/0.4	**34.8/46.1**	0.0/0.0	0.0/0.1	0.0/0.0	0.0/0.3	0.0/0.0	0.3/**6.9**	0.0/0.0	0.0/0.0
AAO024	4	11 778	0.0/0.0	0.0/0.0	0.0/0.4	**20.9/33.1**	0.0/0.0	0.0/0.2	0.0/0.0	0.0/0.9	0.0/0.0	0.0/1.8	0.0/0.0	0.0/0.0
AAJ8913	1	8 913	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**62.9/67.6**	0.0/0.0	0.0/0.0	0.4/3.6	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ8920	1	8 920	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**14.6/22.6**	0.0/0.0	0.0/0.0	0.1/2.2	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ8917	1	8 917	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.1	**45.8/52.0**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ8918	1	8 918	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**11.9/19.3**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9004	2	A 4	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**11.1/18.3**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9209	3	9 209	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**77.2/79.9**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAJ9107	3	9 107	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**23.3/31.2**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAN288		NIST data	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.1	**31.4/39.0**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAN408		NIST data	0.0/0.0	0.0/0.0	0.0/0.9	0.0/0.2	0.0/0.0	0.0/0.0	0.0/0.0	3.2/**10.8**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AAO016	4	11 783	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.3	0.0/0.0	0.0/0.6	0.0/0.1	0.0/0.0	**8.0/18.9**	0.0/0.2	0.0/0.0	0.0/0.0
AAJ9201	3	9 201	0.8/2.0	0.0/0.0	0.0/0.2	0.6/**5.1**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.1	1.5/**12.6**	0.0/0.0	0.0/0.0
AAO006	4	11 764	0.3/1.0	0.0/0.0	0.0/0.0	0.0/1.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.3	1.6/**12.7**	0.0/0.0	0.0/0.0
Compatible with two sources														
AAJ8802	1	8 802	**31.1/35.4**	0.0/0.0	0.0/0.0	**19.6/31.8**	0.0/0.0	0.6/3.5	0.0/0.0	0.0/0.1	0.0/0.2	0.0/0.5	0.0/0.0	0.0/0.0
AAN286		NIST data	**40.6/44.2**	0.0/0.0	0.0/0.0	1.0/**6.4**	0.0/0.0	0.0/0.4	0.0/0.0	0.0/0.0	0.0/2.4	**11.1/28.4**	0.0/0.0	0.0/0.0
AAJ9224	3	9 224	0.2/0.6	0.0/0.0	0.0/0.3	**6.6/17.0**	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.1	0.0/0.1	**38.3/53.7**	0.0/0.0	0.0/0.0
AAJ8905	1	8 905	0.5/1.3	0.0/0.0	0.0/0.0	**9.4/20.6**	0.0/0.0	**5.0/12.0**	0.0/0.0	0.0/0.1	0.0/0.1	0.0/0.1	0.0/0.0	0.0/0.0
AAJ8916	1	8 916	0.3/0.9	0.0/0.0	0.0/0.0	1.3/**7.4**	0.0/0.0	**86.7/88.4**	0.0/0.0	0.0/0.0	**22.5/34.7**	0.0/1.0	0.0/0.0	0.0/0.0
AAJ9003	2	A 3	0.0/0.0	0.0/0.0	0.3/1.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**23.1/34.4**	0.0/0.0	0.0/0.0	0.0/0.0	**34.8/39.8**
Compatible with several sources														
AAJ9110	3	9 110	**22.5/27.1**	0.0/0.0	0.0/0.0	3.2/**11.5**	0.0/0.0	0.0/0.2	0.0/0.0	0.0/0.0	0.3/4.0	**10.5/27.7**	0.0/0.0	0.0/0.0
AAJ9210	3	9 210	**47.3/50.8**	0.0/0.0	0.0/0.0	**95.9/96.6**	0.0/0.0	**43.2/50.7**	0.0/0.0	0.0/0.0	0.4/4.1	0.0/1.3	0.0/0.0	0.0/0.0
AAJ8910	1	8 910	**13.7/17.9**	0.0/0.0	0.0/0.0	**80.5/83.9**	0.0/0.0	**92.4/93.3**	0.0/0.0	0.0/0.0	1.2/**7.2**	0.0/0.8	0.0/0.0	0.0/0.0
AAJ8803	1	8 803	**14.6/18.9**	0.0/0.0	0.0/0.0	**25.3/37.4**	0.0/0.0	**63.6/68.7**	0.0/0.0	0.0/0.0	3.6/**12.4**	0.0/2.4	0.0/0.0	0.0/0.0
AAJ9216	3	9 216	2.3/4.5	0.0/0.0	0.0/0.0	**33.0/44.6**	0.0/0.0	**96.7/97.1**	0.0/0.0	0.0/0.0	4.9/**14.5**	0.0/0.7	0.0/0.0	0.0/0.0
AAJ8907	1	8 907	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	**47.0/53.5**	0.0/0.0	0.0/0.0	**5.0/13.8**	0.0/0.0	0.0/0.0	**32.3/41.7**	0.0/0.0

*References: 1, Hirao *et al.* (1992); 2, Hirao and Enomoto (1993); 3, Hirao and Enomoto (1994); 4, Gale, Stos-Gale and Gilmore (1985).
Specimen AAN406, which is compatible with only Kea and Eastern Artefact Group 2, is listed in Table 6.

six specimens from Kaman-Kalehöyük that relate only to Taurus 2A, all with quite convincingly large probabilities, and Figure 8 shows that the Taurus 2A related artefacts moderately well fill the Taurus 2A field. Table 5 also lists two Kaman-Kalehöyük artefacts that relate uniquely to Taurus 1A, and one that relates only to Taurus 2B. Upon the basis of these unique matches to Central Taurus ore sources, we agree with Hirao *et al.* that the Central Taurus mines are strongly indicated to have been a major source of metal for artefacts found at Kaman-Kalehöyük. Our only disagreements with them are: (1) that they appear to base their conclusions only upon two-dimensional, lead 208/lead 206 versus lead 207/lead 206, plots and that, therefore, some of the artefacts that they relate to Central Taurus metals might not match these metal sources when all three dimensions of the lead isotope data are taken into account; and (2) that the relating to Taurus 1B of specimens that isotopically match Taurus 1B is ambiguous, because these specimens relate to other sources with equal probabilities.

Table 5 lists three artefacts that relate uniquely to Kythnos. Two of these artefacts are from Beycesultan which, being the most western of our archaeological sites, is the one most likely to have received an object from Kythnos. They may indeed have been derived from there but, for the reasons we have cited, the distance of Kythnos from the archaeological sites at which the artefacts were found and the insular nature of Kythnos, this conclusion is somewhat moot.

ISOTOPICALLY CONSISTENT GROUPS OF ARTEFACTS

We have previously commented upon the fact that within a large database of isotopic analyses of artefacts one occasionally finds a group of artefacts whose lead isotope ratios are clustered together and are well separated from those of other artefacts (Sayre *et al.* 1992). The statistical criterion that we have used for defining such groups is that all members of the group have at least 5% probability relative to the group, and that no other artefacts in the database have as great as 5% probability for it. Because the distributions and spreads of such artefact groups, when we have encountered them, have been approximately the same as those of groups of ores and slags from individual sources, we believe it to be very probable that they primarily contain artefacts derived from individual ore sources which have yet to be characterized through isotopic measurement. We have previously defined two such groups of artefacts from Eastern Mediterranean sites. One, which we called Eastern Artefact Group 1, was from sites all well east of the Mediterranean Sea, extending into Mesopotamia. We found no artefacts from the more central Anatolian sites to which we are limiting our present consideration which matched this artefact group. The second group, Eastern Artefact Group 2, included specimens from some central Anatolian sites, including Acemhöyük, Kültepe and Mahmatlar with which we are now concerned. We have found additional artefacts from the sites of Kaman-Kalehöyük and Horoztepe that match this artefact group and an artefact, AAO026, from the southwestern site of Beycesultan, that has small but significant probabilities for this group. The probabilities for the 13 artefacts from the sites of present concern that match the Eastern Artefact Group 2 are listed in Table 6. The complete group, however, now includes 50 additional artefacts from more eastern archaeological sites. An ore specimen from the Aladag mining region of the Taurus Mountains matches the Eastern Artefact 2 Group field, and might possibly be a specimen of a Central Taurus ore source that has not yet been characterized. We now also note that a single ore specimen from Balya, near Balikesir, which was published by Brill and Wampler (1967), and a single slag found at Maltepe Köyü, which was published in Wagner *et al.* (1992), have small but significant probabilities relative to the Eastern Artefact 2 Group.

Two similar isotopically consistent artefact groups were found primarily among the

Table 6 *Artefacts from nearby Anatolian sites with significant probabilities for Central or Eastern 2 Artefact Groups and North Central High Ratio ore specimens*

SI ID	*Data source*		*Probabilities for source group*		
	*Ref.**	*ID*	*Central Artefact*	*Eastern Artefact 2*	*Kea*
Central Artefact Group specimens					
AAJ8923	1	8 923	**47.4/67.0**	0.0/0.0	0.0/0.0
AAJ9104	3	9 104	**79.5/87.0**	0.0/0.0	0.0/0.0
AAJ9120	3	9 120	**21.7/48.5**	0.0/0.0	0.0/0.0
AAJ9230	3	9 230	**33.0/57.2**	0.0/0.0	0.0/0.0
AAJ9231	3	9 231	**55.2/72.0**	0.0/0.0	0.0/0.0
AAJ9236	3	9 236	**79.6/87.0**	0.0/0.0	0.0/0.0
AAJ9243	3	9 243	**33.3/57.5**	0.0/0.0	0.0/0.0
Eastern Artefact 2 Group specimens					
AAJ8925	1	8 925	0.0/1.7	**76.3/77.2**	0.0/0.0
AAJ9105	3	9 105	0.0/2.1	**42.3/44.3**	0.0/0.0
AAJ9208	3	9 208	0.0/1.6	**95.0/95.2**	0.0/0.0
AAJ9227	3	9 227	0.0/1.6	**6.2/7.9**	0.0/0.0
AAJ9249	3	9 249	0.0/1.5	**52.5/54.3**	0.0/0.0
AAN184	NIST data		0.0/1.5	**43.2/45.2**	0.0/0.0
AAN198	NIST data		0.0/2.0	**22.4/24.8**	0.0/0.0
AAN281	NIST data		0.0/1.5	**25.9/28.3**	0.0/0.0
AAN404	NIST data		0.0/1.7	**75.9/76.8**	0.0/0.0
AAN405	NIST data		0.0/1.5	**64.8/66.1**	0.0/0.0
AAN406	NIST data		0.0/1.0	**14.9/17.2**	**37.0/39.5**
AAN407	NIST data		0.0/1.3	**48.5/50.4**	0.0/0.0
AAO026	5	11 781	0.0/1.3	**9.3/11.4**	0.0/0.0
North Central High Ratio ore specimens					
A0J026	4	26	0.0/**9.2**	0.0/0.0	0.0/0.0
AOJ029	4	29	0.0/0.1	0.0/0.0	0.0/0.0
AOJ030	4	30	0.0/0.1	0.0/0.0	0.0/0.0
AOJO38	4	38	0.0/0.0	0.0/0.0	0.0/0.0

References: 1, Hirao *et al.* (1992); 3, Hirao and Enomoto (1994); 4, Hirao *et al.* (1995); 5, Gale, Stos-Gale and Gilmore (1985).

specimens from the site of Kaman-Kalehöyük. One is the Küre Compatible Artefact Group, which contains, together with three specimens from Troy and one from Mersin, 12 artefacts from Kaman-Kalehöyük that range in date from the Hittite through to the Islamic periods. Although the artefacts from Stratum 1 at Kaman-Kalehöyük, which range in date from the present to the fourth century BC, have been excluded from our statistical analysis of probability data, they have been included in this artefact group because they too were probably derived from Küre ores. A number of the ore sources throughout Anatolia have been mined either continuously or in recurrent periods from earliest antiquity to the present day. Artefacts produced during all such mining periods might relate to these metal sources. The three artefact specimens within this group that were excavated at Troy (specimens HDM 251, HDM 261 and HDM 267) were published by Seeliger *et al.* (1985), who noted the similarity of their isotope ratios to those of Küre ores. The fourth matching artefact, found at Mersin, was published by Stos-Gale, Gale and Gilmore (1984; Specimen 17906).

It is moot whether the second cluster of isotopically matching specimens from

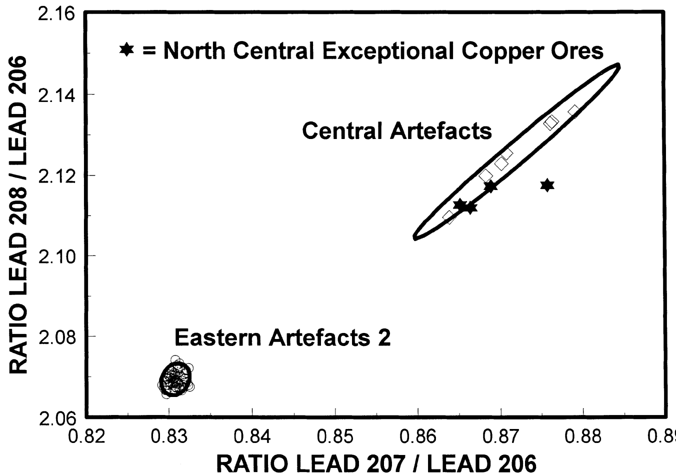

Figure 10 *A stable lead isotope ratio 208/206 versus 207/206 scatter plot for specimens within the Central and the Eastern Artefact groups and the North Central Exceptional Copper ore specimens.*

Kaman-Kalehöyük should be considered to be an established artefact group, because it consists of only seven artefacts. However, the isotope ratios of these seven matching specimens are so exceptionally high and distinct from those of all the other artefacts in our database that we feel that they deserve to be mentioned. Using them as a statistical core group for calculating multivariate probabilities, one finds no other artefacts in our entire database that significantly relate to them and only three ore specimens from Oman, which is too remote geographically to be considered as relating to these artefacts. This group of artefacts, all of which come from Stratum III at Kaman-Kalehöyük, which is dated to the Hittite period (20th to 12th centuries BC), will be called the Central Artefact Group. Isotope ratio plots for this group (Figs 10 and 11) show that it is much more spread out than the Eastern Artefacts 2 Group, which has the compact dimensions of a typical ore source group. The four ore specimens which we have identified as the

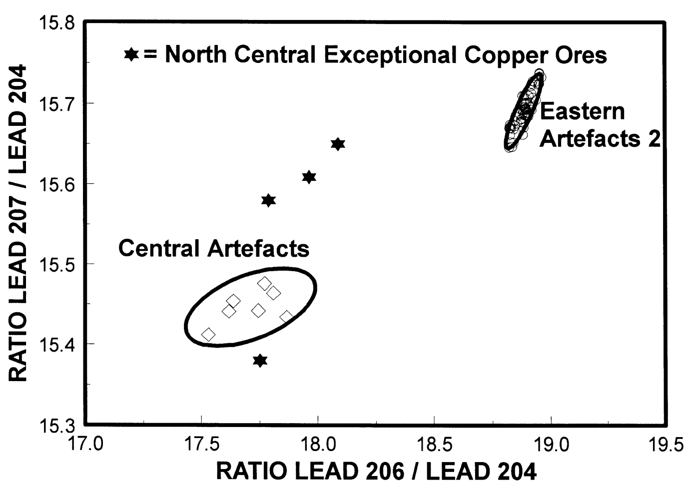

Figure 11 *A stable lead isotope ratio 208/204 versus 207/204 scatter plot for specimens within the Central and the Eastern Artefact groups and the North Central Exceptional Copper ore specimens.*

North Central Exceptional Ore Specimens have similar high ratios relative to lead 206 and in a lead 208/lead 206 versus lead 207/lead 206 plot (Fig. 10) they largely coincide with the Central Artefact Group field. Based upon this two-dimensional coincidence, Hirao *et al.* related these ores and artefacts to each other. However, plots and statistical evaluations that include ratios relative to lead 204 show that in the full three-dimensional lead isotope space the North Central Exceptional ores are not significantly related to the Central Artefact Group artefacts. Figure 11, a lead 207/lead 204 versus lead 206/lead 204 plot, shows that these ores lie well outside of the Central Artefact field; and Table 6, which includes the probabilities of the North Central Exceptional ores relative to Central Artefact Group, shows that these probabilities are not significantly high.

CONCLUSIONS

Stable lead isotope determination has not proved to be a perfect method of relating ancient artefacts to metallic ore sources from which they may have been derived. However, if the complete information available in the measurements of the relative proportions of all four of the stable isotopes of lead—lead 208, lead 207, lead 206 and lead 204—is fully utilized, the origins of many individual artefacts can often be inferred with a reasonably high degree of probability. The problems that have arisen with the method are due primarily to the fact that many of the isotope ratio fields associated with different ore sources are not fully resolved from each other. The degree of overlap among group isotope ratio fields varies from that of the Laurion ores, which to the best of our present information is uniquely separate from others, to the Taurus 1B ore field, which is so badly overlapped by other fields that it is unlikely that an individual artefact could be related uniquely to it. Fortunately, however, most of the source groups that now have been characterized are fairly well resolved from each other, in the full three-dimensional isotope ratio space, with only a moderate amount of mutual overlap. A case in point is the North Central Anatolia ore field, that overlaps to some degree with nine other ore source groups, but for which we have found 34 artefacts, listed in Table 2, which have statistical probabilities relative only to it. This can only happen if a significant portion of the North Central Anatolia ore field is well resolved from the nine other fields. Tables 1 and 5 together list an additional 33 artefacts that relate to only to other single ore sources, and Table 6 lists 19 more artefacts that significantly relate only to one of two isotopically well characterized and well resolved artefact groups, whose ore sources have not yet been determined. As was pointed out earlier, these uniquely related artefacts add up to more than half of the artefacts that statistically related to any of the presently established ore or artefact groups. Among the many artefacts that relate to just two source groups, the differences in probabilities relative to the two groups and other factors often indicate one of the two sources to be definitely more probable. Therefore, despite the complexities encountered, origins of reasonable probability have been indicated for a significant fraction of the artefacts analysed. There were indeed 14 artefacts encountered, listed in Tables 1, 4 and 5, which individually related to three or more sources. These isotopically ambiguous artefacts, however, constitute a reasonably small fraction of the number considered, and there is still some archaeological significance to be drawn from their measurements. At the very least, only a limited number of sources has been indicated for them.

No matter how probable the inference might be that a particular artefact was or was not derived from a particular ore source, it can never be claimed that the isotope ratio data prove beyond any doubt that the object was or was not made of metal from that source. However, when one has a number of related artefacts all showing the same correlation with an origin, the collective evidence becomes very persuasive. The fact that Tables 2, 3 and 4 list 76 artefacts that might possibly be derived from North Central Anatolia ores, because their isotope ratios are consistent with the North Central ore field, of which 34, listed in Table 2, quite probably were derived from North Central ore, because their isotope ratios are consistent only with the North Central ore field, provides massive collective evidence that the North Central mines were the major source of metals for the archaeological sites located nearby to them, as one might expect them to be. The sizable number of artefacts listed in Table 1 with unique or predominate probabilities for the Trabzon Ore Group and for the Küre Compatible Artefact Group provide convincing collective evidence that the Trabzon and Küre mines were also sources of metals for these archaeological sites. Also, the sizable number of artefacts shown in Figure 9 to have isotopic ratios intermediate between those of the North Central and Trabzon fields provide collective evidence that the Trabzon and North Central metals were sometimes mixed together in the formation of artefacts, despite the fact that some of these intermediate artefacts lie within the Artvin Ore field. It is unfortunate that the Artvin Ore field lies so totally intermediate between the Trabzon and North Central that one can never be sure whether an object compatible with it might not have been formed from the mixing of metals from the other two groups of mines. One can conclude only that it is possible that the Artvin ores were being mined during the periods under consideration.

Considered together, the nine specimens in Table 5 that have significant probabilities only for the Taurus 1A, Taurus 2A or Taurus 2B ores provide a strong indication that metals in these objects were indeed from the Central Taurus region. They also make it more probable that the seven artefacts listed in Table 3 which have significant probabilities only for North Central and Taurus 1B or 2A do relate to the Taurus ores, particularly since most of them have higher probabilities for Taurus than for North Central. The specimens in Table 5 which show unique probabilities relative to Cyprus 2C, Kythnos 1, Laurion, Troad 1 and Troad 2 provide collective evidence that there probably was some exchange of objects from more remote sources. The overall picture of metal trade in Central Anatolia from the Bronze Age to the Phrygian to be derived from the lead isotope ratio data is one of a modest amount of fairly distant exchange throughout the Eastern Mediterranean region, but with a large preponderance of metal objects being derived from mines located close to the sites at which the objects were found, which is exactly what one would have expected.

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APPENDIX A

Catalogue of Black Sea specimens analysed at NIST

North Central Anatolia Ore Group Specimens

AON254	Şebinkarahisar/Sisorta/Kavala, near Sivas. Galena sample taken from modern Kavala Mine ore heap.
AON316	Merzifon/Gümüş Bucağı, Inegöl north, Karlı Doruk mountain. Galena sample taken from remains of a closed ancient mine.
ASN322	Merzifon/Gümüşhacı Köy slag dump. Thousands of tons of lead smelting slags in the modern town.
AON328	Ünye/Kumarlı, Karadere region. Galena–sphalerite sample.
AON331	Fatsa/Çıtelli, Tepetarla. Galena sample taken from ore specimens left in front of two old workings at Azapoğlu kayası.
AON334	Ordu/Gölköy, Çıtelli Kale Deresi. 70 km south of Ordu. Galena sample taken from the remains of a closed ancient mine.
AON335	Giresun/Buluncak, Yukarıtekmezar region. Galena–sphalerite samples taken from ore heap in front of a modern mine.
AON340	Giresun/Tirebolu (Inköy), Galena–sphalerite sample from the modern mine, Demir Export Co.
AON344	Giresun/Espiye. Galena–sphalerite sample taken in Espiye brought in from the Ahilbaba region mines.
AON412	Giresun/Tirebolu. Powdered galena sample obtained from Maden Tetkik Arama Genel Müdürlüğü (MTA, Turkish Geological Survey, Ankara), no. 375. From Haşit river basin.
AON435	Ankara/Kızılcahaman/ Işık Dağ. Jamesonite sample.
ASN17104	Trabzon/Gümüşhane slag heap sample.
ASN17107	Giresun/Tirebolu, slag sample from slag dump where Haşit river flows into the Black Sea.
AON17203	Merzifon/Gümüş Bucağı, Aşağı Ovacık village, Galena sample taken from a modern mine directly towards the lower levels of ancient mines on Inegöl mountain.
AON18762	Giresun/Tirebolu. Galena–sphalerite sample obtained from modern mine, Demir Export Co.
AON18763	Giresun/Tirebolu. Galena–sphalerite sample from modern mine, Demir Export Co.
AON18764	Giresun/Tirebolu. Galena–sphalerite sample from modern mine, Demir Export Co.
ASN18765	Merzifon/Gümüşhacı Köy slag dump. Same place as ASN 322, metallic appearence, spiess.
AON18766	Merzifon/Gümüşhacı Köy, Deligözler Köyü. Galena sample taken from remains from collapsed ancient mines west of village.
ASN18767	Merzifon/Gümüşhacı Köy, Deligözler Köyü. Galena–pyrite sample taken from same location as sample AON18766.
ASN18770	Merzifon/Gümüş Bucağı, Kuyucak yaylası, Kelahmet Mevkii. Galena sample taken from slag heap spread over a wide area. Sample is heavy, metallic slag, spiess.

Table 7 *Lead Isotope Ratios of Black Sea Ore Specimens*

Sample	*Laboratory*	*Find site*	*Nature*	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$
North Central Anatolia Ore Group—published specimens						
(PHA)G208	Kouvo[1]	Haviyana	Galena	2.0770	0.8391	0.05382
(PHA)G209	Kouvo[1]	Gümüşhane/Hazine	Galena	2.0729	0.8391	0.05362
(PHA)G210	Kouvo[1]	Daridere	Galena	2.0714	0.8369	0.05365
(PHA)G213	Kouvo[1]	Sebinkarahisar/Sisorto	Galena	2.0742	0.8402	0.05382
32	Tokyo[2]	Sebinkarahisar/Asarcık	Azurite pyrite	2.0743	0.8371	0.05366
40	Tokyo[2]	Tokat-Almus/Bakımlı	Slag	2.0736	0.8367	0.05356
TG 159B-1	Mainz[3]	Ankara/Işık Dağ-Maden Boğazi	Galena	2.0716	0.8355	0.05349
TG 164A-2	Mainz[3]	Derealan/Bakır Çay	Galena	2.0765	0.8376	0.05362$_1$
TG 165B	Mainz[3]	Merzifon/Gümüşhacıköy	Galena	2.0710	0.8352	0.05347
TG 170A-1	Mainz[3]	Tirebolu/Harşıt Köprübaşı	Galena	2.0758	0.8390	0.05365
TG 171A-1	Mainz[3]	Gümüşhane-Hazıne/Mağara	Galena	2.0771	0.8396	0.05368
TG 172-2	Mainz[3]	Gümüşhane/Karadağ	Slag (copper)	2.0755	0.8373	0.05358
TG 172-3	Mainz[3]	Gümüşhane/Karadağ	Copper ore	2.0758	0.8374	0.05361
TG 198	Mainz[4]	Sebinkarahisar/Sis Orta	Galena	2.0736	0.8390	0.05370
TG 202-A	Mainz[5]	Ordu/Tekmezar-Eriklik	Copper ore	2.0731	0.8378	0.05354
TG 202-A1	Mainz[5]	Ordu/Tekmezar-Eriklik	Slag (copper)	2.0731	0.8374	0.05344
TG 207-A	Mainz[5]	Kürtün/Çayırçukur	Copper ore	2.0786	0.8398	0.05371
TG 207-G1	Mainz[5]	Kürtün/Çayırçukur	Copper ore	2.0744	0.8374	0.05349
SI-NIST North Central Ore Group specimens						
AON254	NIST	Sebinkarahisar/Sisorta/Kavala	Galena	2.0748	0.8390	0.05380
AON316	NIST	Merzifon/Gümüşbucağı	Galena	2.0747	0.8350	0.05348
ASN322	NIST	Merzifon/Gümüşhacıköy	Lead slag	2.0757	0.8353	0.05353
AON328	NIST	Ünye/Kumarlı, Kadadere	Galena–sphalerite	2.0732	0.8374	0.05369
AON331	NIST	Ünye Fatsa/Çitelli Kale Deresi	Galena	2.0763	0.8369	0.05356
AON334	NIST	Ordu/Gölköy	Galena	2.0740	0.8360	0.05350
AON335	NIST	Giresun/Bulancak/Yukaritekmezar	Galena–sphalerite	2.0755	0.8386	0.05380
AON340	NIST	Giresun/Tirebolu (Inköy)	Galena–sphalerite	2.0772	0.8374	0.05357
AON344	NIST	Giresun/Tirebolu Espiye	Galena–sphalerite	2.0776	0.8388	0.05368
AON412	NIST	Giresun/Tirebolu	Galena	2.0768	0.8383	0.05355
AON435	NIST	Ankara/Kizicahaman/Işık Dağ	Jamesonite	2.0780	0.8379	0.05346
ASN17 104	NIST	Gümüşhane	Slag	2.0738	0.8358	0.05334
ASN17 107	NIST	Giresun/Tirebolu	Slag	2.0755	0.8371	0.05339
AON17 203	NIST	Merzifon/Gümüşbucağı	Galena	2.0739	0.8356	0.05350
AON18 762	NIST	Giresun/Tirebolu	Galena–sphalerite	2.0742	0.8373	0.05353
AON18 763	NIST	Giresun/Tirebolu	Sphalerite	2.0744	0.8370	0.05349
AON18 764	NIST	Giresun/Tirebolu	Galena–sphalerite	2.0756	0.8376	0.05344
ASN18 765	NIST	Merzifon/Gümüşhacıköy	Slag	2.0729	0.8354	0.05357
AON18 766	NIST	Merzifon/Gümüşhacıköy	Galena	2.0720	0.8347	0.05342
AON18 767	NIST	Merzifon/Gümüşhacıköy	Galena–pyrite	2.0718	0.8343	0.05329
ASN18 770	NIST	Merzifon/Gümüşbucağı	Galena slag	2.0728	0.8353	0.05352
North Central Exceptional Copper Ores—published specimens						
26	Tokyo[2]	Merzifon/Amasya	Native copper	2.1120	0.8664	0.05633
29	Tokyo[2]	Çankiri/Urvayköy Yapraklı	Native copper	2.1173	0.8689	0.05567
30	Tokyo[2]	Çorum/Bayat	Native copper	2.1127	0.8652	0.05429
38	Tokyo[2]	Çorum/Kuvarshan	Azurite	2.1176	0.8758	0.05621

Table 7 *(continued)*

Sample	*Laboratory*	*Find site*	*Nature*	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$
Trabzon Ore Group—published specimens						
(PHA)G207K	Kouvo[1]	Kostere	Galena	2.0888	0.8462	0.05414
33	Tokyo[2]	Giresun-Tirebolu/Harköy	Chalcopyrite	2.0865	0.8443	0.05394
42	Tokyo[2]	Trabzon/Maçka	Chalcopyrite	2.0890	0.8441	0.05387
TG 166A	Mainz[3]	Ordu/Piraziz-Madenköy	Galena	2.0861	0.8442	0.05394
TG 167A-1	Mainz[3]	Eseli Maden	Ore (lead)	2.0884	0.8462	0.05426
TG 173-1	Mainz[3]	Gümüşhane/Zankar	Ore (lead)	2.0892	0.8450	0.05410
TG 201-A	Mainz[5]	Trabzon/Kayabaşı-Köyü	Ore (copper)	2.0890	0.8465	0.05412
TG 201-D	Mainz[5]	Trabzon/Kayabaşı-Köyü	Ore (copper)	2.0898	0.8470	0.05422
TG 201-C1	Mainz[5]	Trabzon/Kayabaşı-Köyü	Slag (copper)	2.0827	0.8428	0.05393
TG 204	Mainz[5]	Karaerik	Ore (copper)	2.0843	0.8452	0.05416
TG 206-A	Mainz[5]	Lahanos Maden	Ore (copper)	2.0833	0.8448	0.05422
TG 206-B	Mainz[5]	Lahanos Maden	Slag (copper)	2.0848	0.8449	0.05420
TG 207-C	Mianz[5]	Kürtür/Çayırçukur	Slag (copper)	2.0854	0.8442	0.05408
TG 212-A	Mainz[5]	Rize/Madenli-Çayeli	Ore (copper)	2.0873	0.8471	0.05442
TG 212-B1	Mainz[5]	Rize/Madenli-Çayeli	Slag (copper)	2.0882	0.8473	0.05447
Trabzun Ore Group—unpublished specimens						
AON17108	NIST	Giresun/Tirebolu	Chalcopyrite	2.0854	0.8449	0.05428
PB 117	BNL[6]	Zigana/Gümüşhane	Galena	2.0923	0.8464	0.05408
Artvin Ore Group—published specimens						
Pb 118	BNL[7]	Artvin/Yukari Madenköy	Galena	2.0821	0.8433	0.05403
TG 211-A1	Mainz[5]	Artvin/Murgul	Chalcopyrite	2.0807	0.8413	0.05386
TG 211-A2/1	Mainz[5]	Artvin/Murgul	Chalcopyrite	2.0818	0.8422	0.05398
TG 211-A2/2	Mainz[5]	Artvin/Murgul	Mixed copper ores	2.0821	0.8424	0.05395
TG 211-A3	Mainz[5]	Artvin/Murgul	Decomposed Cu ores	2.0834	0.8427	0.05394
TG 211-B/1	Mainz[5]	Artvin/Murgul	Chalcopyrite	2.0789	0.8409	0.05390
TG 211-B/2	Mainz[5]	Artvin/Murgul	Chalcopyrite	2.0786	0.8412	0.05395
TG 211-1	Mainz[5]	Artvin/Murgul	Slag (copper)	2.0825	0.8426	0.05394
TG 211-3	Mainz[5]	Artvin/Murgul	Slag (copper)	2.0816	0.8423	0.05397
TG 211-17	Mainz[5]	Artvin/Murgul	Slag (copper)	2.0821	0.8426	0.05396
TG 211-19	Mainz[5]	Artvin/Murgul	Slag (copper)	2.0811	0.8419	0.05393
TG 211-25	Mainz[5]	Artvin/Murgul	Slag (copper)	2.0825	0.8424	0.05392
TG 213	Mainz[5]	Artvin/Ilıcaçermik-Kuabukar	Slag (copper)	2.0835	0.8426	0.05392
TG 215-B	Mainz[5]	Artvin/Gümüşhane	Azurite	2.0820	0.8401	0.05391
TG 215-E1	Mainz[5]	Artvin/Gümüşhane	Slag (copper)	2.0807	0.8397	0.05381
Küre Ore Group—published specimens						
(ORD)G204	Kuovo[1]	Western Turkey	Galena	2.0918	0.8520	0.05462
34	Tokyo[2]	Aşıköy Küre Kastamonu	Chalcopyrite	2.0904	0.8489	0.05432
TG 162A-1	Mainz[3]	Küre	Copper pyrites	2.0877	0.8484	0.05430
TG 162B-1	Mainz[3]	Küre	Copper pyrites	2.0920	0.8516	0.05466
TG 162C-2	Mainz[3]	Küre	Copper slag	2.0882	0.8491	0.05434
TG 162E	Mainz[3]	Küre	Copper slag	2.0869	0.8474	0.05430

[1] Published in Kouvo (1976).
[2] Published in Hirao *et al.* (1995).
[3] Published in Seeliger *et al.* (1985).
[4] Published in Wagner *et al.* (1986).
[5] Published in Wagner *et al.* (1992).
[6] Personal communication from R. H. Brill. Analysed by J. M. Wampler at Brookhaven National Laboratory (BNL).
[7] Published in Brill and Wampler (1967).

Trabzon Ore Specimen

ASN17108 Giresun/Tirebolu. Chalcopyrite sample from modern mine, Demir Export Co.

Catalogue of artefact specimens analysed at NIST

AAN198 Silver fragment, Horoztepe, Early Bronze Age graves. Anatolian Civilizations Museum, Ankara. Özgüç and Akok (1958).
AAN008 Lead pendant. Alişar Copper Age (Early Bronze II). Anatolian Civilizations Museum, Ankara. Excavation Register No. c753. Von der Osten (1937a, Fig. 197).
AAN924 Lead ring. Alişar period II (MBA), Plot II 1387. Oriental Institute Register No. A6248. Von der Osten and Schmidt (1932, 103).
AAN925 Lead ring, thin coil. Alişar period II (MBA), 1325. Oriental Institute Register No. A6234. Von der Osten and Schmidt (1932, 103).
AAN926 Lead ring with round section, open ends. Alişar period II (MBA), Plot XV, −5.80 depth. Oriental Institute Register No. A6474. Excavation Register No. 2496. Von der Osten and Schmidt (1932, 103).
AAN927 Copper-based ring. Alişar Oriental Institute Register No. A10827a. Excavation Register number Grave X32. Von der Osten (1937a, Fig. 23).
AAN199 Lead fragment. Kültepe Middle Bronze Age. Anatolian Civilizations Museum, Ankara.
AAN281 Iron ingot or bloom. Kültepe Ia (Old Hittite). Sample from excavator Kutlu Emre. Ankara.
AAN183 Silver fragment. Acemhöyük Middle Bronze Age hoard. Sample from excavator, N. Özgüç, Özten (1997).
AAN184 Silver fragment. Acemhöyük Middle Bronze Age hoard. Sample from excavator, N. Özgüç. Yener *et al*. (1991), Özten (1997).

Table 8 *Compositions of unpublished Black Sea ores and slags*

Sample	*Concentrations of elements (percentages except for gold)*											
	Lead	*Zinc*	*Copper*	*Iron*	*Arsenic*	*Antimony*	*Cobalt*	*Nickel*	*Tin*	*Bismuth*	*Silver*	*Gold (ppm)*
North Central Anatolia Ore Group specimens												
AON254	70.3	11.7	0.13	1.87	n.d.	n.d.	n.d.	0.02	n.d.	*	0.006	0.20
AON328	5.91	23.4	0.03	0.68	0.01	n.d.	n.d.	n.d.	n.d.	*	n.d.	0.43
AON316	35.8	6.49	0.12	16.9	0.81	0.11	n.d.	0.01	n.d.	*	n.d .	0.33
AON334	20.0	32.4	0.543	1.42	0.01	0.02	n.d.	n.d.	n.d.	*	n.d.	0.89
ASN322	2.11	1.24	1.15	38.5	4.00	1.85	n.d.	0.07	n.d.	*	n.d.	0.85
AON18 766	18.8	1.01	0.24	9.03	0.47	0.15	n.d.	0.01	n.d.	0.02	0.047	1.00
AON17 203	40.5	0.30	0.08	5.69	4.22	0.16	n.d.	n.d.	n.d.	0.02	0.078	1.51
AON331	70.9	5.38	0.49	2.02	0.02	0.01	n.d.	n.d.	n.d.	*	n.d.	0.57
AON335	30.4	23.1	1.65	4.66	0.02	0.01	n.d.	0.01	n.d.	*	n.d.	n.d.
AON340	6.86	17.4	3.46	10.2	0.72	1.86	n.d.	0.01	n.d.	*	n.d.	0.57
AON344	37.2	29.1	0.80	2.16	0.01	n.d.	n.d.	0.01	n.d.	*	n.d.	0.79
AON412	19.3	23.6	2.12	8.98	0.76	1.58	n.d.	n.d.	0.091	*	0.080	1.25
AON18 764	13.1	22.6	3.03	5.42	0.79	0.10	n.d.	n.d.	n.d.	0.01	n.d.	0.07
AON18 763	19.7	22.3	4.67	3.46	0.49	2.66	n.d.	n.d.	n.d.	0.01	0.017	2.85
AON435	1.82	0.01	n.d.	22.1	0.01	0.11	n.d.	n.d.	0.029	*	0.080	17.0
ASN17 107	4.99	5.78	7.16	26.11	0.74	0.42	0.01	0.02	*	n.d.	0.029	*
ASN18 770	12.9	0.58	4.77	43.42	25.34	0.43	0.02	0.05	n.d.	n.d.	0.021	n.d.
ASN18 767	6.72	0.32	0.07	14.4	0.43	0.06	0.01	0.02	n.d.	0.01	0.011	5.53
ASN18 765	1.01	1.65	0.90	57.31	31.73	0.69	0.02	0.02	*	n.d.	0.020	n.d.
Trabzon Ore Group specimens												
ASN17 108	2.44	7.11	12.10	19.5	1.00	2.17	n.d.	n.d.	n.d.	0.02	0.025	2.80

n.d., Not detected; *, not determined.

Table 9 *Lead isotope ratios of SI-NIST Anatolian artefact specimens*

Sample	*Laboratory*	*Find site*		*Nature*	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$
From site of Horoztepe							
AAN198	6	MAC	–	Silver fragment	2.0676	0.8307	0.05307
From site of Alişar							
AAN008	3	MAC	c753	Lead pendant	2.0715	0.8336	0.05327
AAN924	2	OIM	A6248	Lead ring	2.0742	0.8352	0.05344
AAN925	nm	OIM	A6234	Lead ring	2.0841	0.8433	0.05372
AAN926	2	OIM	A6474	Lead ring	2.0741	0.8353	0.05345
AAN927	3	OIM	A10827a	Copper-based ring	2.0743	0.8349	0.05324
From site of Kültepe							
AAN199	nm	MAC	–	Lead fragment	2.0773	0.8386	0.05223
AAN281	6	MAC	–	Iron ingot or bloom	2.0666	0.8316	0.05306
From site of Acemhöyük							
AAN183	nm	NM	–	Silver fragment	2.0690	0.8275	0.05245
AAN184	6	NM	–	Silver fragment	2.0697	0.8306	0.05281
AAN271	nm	MTA	30	Lead ore nodule	2.0861	0.8443	0.05372
AAN282	nm	NM	3.415-81	Copper ingot	2.0950	0.8550	0.05476
AAN286	5	NM	3.412-81	Copper ingot	2.0693	0.8348	0.05327
AAN288	5	MTA	32	Arsenical ore nodule	2.0775	0.8389	0.05344
AAN840	nm	AU	17111	Lead fragment	2.0661	0.8331	0.05297
AAN841	1	AU	17112	Lead pendant	2.0826	0.8416	0.05383
AAN842	3	AU	17113	Copper pin	2.0770	0.8376	0.05348
AAN843	1	AU	17098	Copper pin	2.0805	0.8400	0.05382
AAN17 095	2	AU	–	Copper ore	2.0791	0.8408	0.05369
AAN17 096	2	AU	–	Slag from crucible	2.0752	0.8367	0.05344
From site of Karahöyük							
AAN2032	2	KM	–	Copper slag	2.0736	0.8358	0.05350
From site of Alaca							
AAN007	2	MAC	–	Silver bowl with snakes	2.0750	0.8370	0.05336
From site of Mahmatlar							
AAN404	6	MAC	112-14-64	Silver ingot	2.0680	0.8301	0.05287
AAN405	6	MAC	112-22-64	Silver ingot	2.0680	0.8305	0.05286
AAN406	6	MAC	112-10-64	Silver ingot	2.0672	0.8317	0.05294
AAN407	6	MAC	112-8-64	Silver ingot	2.0673	0.8309	0.05289
AAN408	5	MAC	112-5-64	Silver ingot	2.0662	0.8318	0.05287
AAN409	nm	MAC	112-11-64	Silver ingot	2.0689	0.8314	0.05278

nm, Non-matching artefact that does not statistically relate to any of the present ore groups.

MAC, Museum of Anatolian Civilizations (Ankara); OIM, Oriental Institute Museum; NM, Nidğe Museum; MTA, Turkish Geological Survey (Maden Tetket Arama Genel Müdürlüğü); AU, Ankara University; KM, Konya Museum.

AAN271 Lead ore. Acemhöyük Middle Bronze Age. Sample from MTA, No. 30. Ergun Kaptan.

AAN282 Copper ingot. Acemhöyük Middle Bronze Age. Excavation Register AC.1 57. Niğde Museum Register 3.415-81.

AAN286 Copper ingot. Acemhöyük Middle Bronze Age. Excavation Register AC.1 54. Niğde Museum Register 3.412-81. Sayre *et al*. (1992).

AAN288 Arsenic ore. Acemhöyük Middle Bronze Age. Sample from MTA, No. 32. Ergun Kaptan.

Table 10 *Compositions of unpublished Anatolian artefacts*

Sample	*Concentrations of elements (percentages except for gold)*											
	Lead	*Zinc*	*Copper*	*Iron*	*Arsenic*	*Antimony*	*Cobalt*	*Nickel*	*Tin*	*Bismuth*	*Silver*	*Gold (ppm)*
From site of Horoztepe												
AAN198	0.34	0.19	5.64	0.50	n.d.	0.06	n.d.	0.02	n.d.	*	3.77	3667.
From site of Alişar												
AAN008	95.0	2.13	n.d.	1.15	n.d.	0.13	0.05	0.25	n.d.	*	0.08	384.
From site of Kültepe												
AAN199	99.0	0.03	0.07	0.17	n.d.	n.d.	n.d.	0.84	n.d.	*	0.05	10.8
AAN281	n.d.	0.03	2.36	29.10	0.04	n.d.	n.d.	0.04	n.d.	*	0.03	7.47
From site of Acemhöyük												
AAN183	2.98	0.53	0.57	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	*	76.2	184.
AAN184	n.d.	0.14	1.66	0.47	0.01	n.d.	n.d.	0.08	n.d.	*	71.8	1918.
AAN271	93.7	0.02	0.02	0.05	0.01	n.d.	n.d.	0.02	n.d.	*	0.03	4.48
AAN282	n.d.	0.02	44.7	1.71	0.41	0.04	n.d.	0.04	n.d.	*	0.08	37.0
AAN286	n.d.	0.03	61.4	0.72	0.07	0.06	0.10	0.68	n.d.	*	0.01	3.77
AAN288	12.0	0.07	15.5	9.04	5.76	0.12	n.d.	0.04	n.d.	*	0.04	15.3
AAN840	0.3	0.01	41.4	0.37	0.30	n.d.	n.d.	0.01	9.4	n.d.	0.05	14.0
AAN841	98.5	0.02	0.01	0.04	0.78	0.05	n.d.	0.01	n.d.	0.05	n.d.	9.37
AAN842	0.57	0.14	90.8	0.15	1.39	n.d.	n.d.	0.01	0.25	n.d.	0.01	8.75
AAN843	n.d.	0.78	66.0	0.49	0.02	n.d.	n.d.	0.01	n.d.	n.d.	0.01	4.36
AAN17095	n.d.	n.d.	54.4	0.21	0.26	0.04	n.d.	0.46	n.d.	0.01	n.d.	4.60
AAN17096	n.d.	0.15	22.8	6.62	0.13	0.02	n.d.	0.01	n.d.	0.02	n.d.	1.69
From site of Alaca												
AAN007	0.15	0.18	0.16	0.12	0.10	n.d.	n.d.	0.01	n.d.	*	70.4	2370.
From site of Mahmatlar												
AAN404	0.13	0.01	1.09	0.08	n.d.	n.d.	n.d.	n.d.	n.d.	*	95.3	770.
AAN405	0.11	0.02	1.40	0.05	0.01	n.d.	n.d.	n.d.	0.30	*	90.0	1518.
AAN406	0.21	6.22	2.41	0.12	0.02	n.d.	n.d.	n.d.	0.77	*	90.0	176.
AAN407	0.15	13.1	1.99	0.17	n.d.	n.d,	n.d.	n.d.	0.62	*	90.0	886.
AAN408	0.17	0.17	3.09	0.30	0.01	n.d.	n.d.	0.10	0.33	*	94.8	1896.
AAN409	0.12	0.08	1.72	0.02	n.d.	n.d.	n.d.	n.d.	0.24	*	90.5	2680.

n.d., Not detected; *, not determined.

AAN840	Lead fragment. Acemhöyük Middle Bronze Age, SA/42 p2. II Kat evi. Excavation Register 17111. Sample from excavator, Aliye Özten.
AAN841	Lead pendant. Acemhöyük Middle Bronze Age, SA/42 p2 II Kat evi. Excavation Register No. 17112. Sample from excavator, Aliye Özten.
AAN842	Copper-based pin. Acemhöyük Middle Bronze Age, UA/33 III Kat. Excavation Register No 17113. Sample from excavator, Aliye Özten.
AAN843	Copper-based pin. Acemhöyük Middle Bronze Age, Ac90 2A/42. Excavation Register No. 17098. Sample from excavator Aliye Özten.
AAN17095	Ore. Acemhöyük Middle Bronze Age, ZA/43 II Kat. Sample from excavator, Aliye Özten.
AAN17096	Crucible slag. Acemhöyük Middle Bronze Age. III Kat. Sample from excavator, Aliye Özten.
AAN2032	Copper slag. Karahüyük Konya. Middle Bronze Age (Ib). Sample from excavator, Sedat Alp.
AAN007	Fragment from silver vessel decorated with snakes in relief. Alaca Höyük Early Bronze Age Tomb K. Excavation Register No. 41. Anatolian Civilizations Muzeum, Ankara. Koşay (1951), Plate 178; Yener *et al*. (1991).

AAN404 Silver ingot, 424 g. Mahmatlar (Early Bronze Age). Museum Register No. 112-14-64. Excavation Register No. 10. Koşay and Akok (1950), Yener *et al.* (1991).

AAN405 Silver ingot, 394 g. Mahmatlar (Early Bronze Age). Museum Register No. 112-22-64. Excavation Register No. 18. Koşay and Akok (1950), Yener *et al.* (1991).

AAN406 Silver ingot, 416 g. Mahmatlar (Early Bronze Age). Museum Register No. 112-10-64. Excavation Register No. 6. Koşay and Akok (1950), Yener *et al.* (1991).

AAN407 Silver ingot, 426 g. Mahmatlar (Early Bronze Age). Museum Register No. 112-8-64. Excavation Register No. 4. Koşay and Akok (1950), Yener *et al.* (1991).

AAN408 Silver ingot, 4640 g. Mahmatlar (Early Bronze Age). Museum Register No. 112-5-64. Excavation Register No. 1. Koşay and Akok (1950), Yener *et al.* (1991).

AAN409 Silver ingot, 428 g. Mahmatlar (Early Bronze Age). Museum Register No. 112-11-64. Excavation Register No. 7. Koşay and Akok (1950), Yener *et al.* (1991).

APPENDIX B

Note on the new stable lead isotope data for the Central Taurus ore sources

In the paper 'Stable lead isotope studies of Central Taurus ore sources and related artifacts from Eastern Mediterranean Chalcolithic and Bronze Age sites' (Yener *et al.* 1991), it was pointed out that lead isotope ratios of specimens of ores and slags from ancient mining sites throughout the Central Taurus Mountains in Turkey primarily separated into four isotope ratio fields. The ore fields that were substantially from the more southwestern sites of Esendemirtepe and the Bolkardağ Valley were identified as Taurus 1A and Taurus 1B, and those that substantially came from the more northeastern sites of Yahyalı and the Aladağ Mountains were called Taurus 2A and Taurus 2B. Both the Taurus 1B and Taurus 2B groups contained additional specimens from the intermediate Camardı-Niğde Massif region, and Taurus 1B group also contained a specimen of slag from the mining region north of Yahyalı.

The original Taurus 1A and Taurus 2A groups were reasonably well defined, with 16 and 12 specimens respectively. The original Taurus 1B and Taurus 2B, however, were only marginally well defined, with eight and six specimens respectively. Accordingly, we have sought out for analysis at the National Institute of Standards and Technology (NIST) five additional specimens belonging to each of these two groups. We also have elemental analyses for these specimens and for an additional one that we encountered whose isotope ratios did not match one of the defined groups. In addition Hirao *et al.* (1995) have recently published lead isotope ratio data on a number of ore specimens from mining sites throughout Turkey, including 21 specimens from Central Taurus sites, and Wagner *et al.* (1992) have published four analyses of Central Taurus ores. Brill and Wampler (1967) had published an lead ore specimen from Akdağmadeni, which we now feel should be included with the Central Taurus ores. Except for five non-matching outlying specimens, the new specimens now conform well to the previously defined Taurus ore fields. The Taurus groups are all now well defined by sample sizes ranging from 15 to 21 specimens, with an average of 18.5 specimens per group. Because there has been considerable interest in these groups, resulting in their having been cited in a number of papers, we have thought it worthwhile to bring together all of the new data, with our own unpublished data, for the use of all those concerned with these ore fields.

The new isotope ratio data, listed in Table 11, correspond well with the data that we published originally. Figure 12 shows how well the new isotope ratios overlap the original ones. In this plot, the four ore fields are inclosed with 90% probability enclosure ellipses, the original data points being indicated by open circles and the new data points by solidly filled in black circles. The positions and spreads of the ore source fields have not been altered significantly by the addition of the new data. Hirao *et al.* (1995) have similarly demonstrated the coincidence between their data points and ours.

There were, however, some significant expansion of the geographical areas over which specimens some of the Central Taurus group specimens were found. The Taurus 1A group showed no such expansion, all of the new specimens coming from the Bolkardağ Valley as had the original specimens. Four new Taurus 1B specimens were from the sites from which original Taurus 1B specimens had been obtained; that is, Bolkardağ/Sulucadere, Esendemirtepe/Ulukısla and the mining region north of Yahyalı. It is worth noting, however, that, while originally there was only a slag specimen from Yahyalı that matched this group, Hirao *et al.* analysed two matching galena ores from this region, demonstrating that Taurus 1B ores did indeed extend this far north. A new development, however, was the encountering of six specimens from the mining site of Akdağmadeni, another 100 km north-east of Yahyalı, that closely match the Taurus 1B isotope ratios. We had noted in our previous paper that the lead ore from Akdağmadeni, Pb 85, that had been published by Brill and Wampler (1967) had a high probability of matching Taurus 1B, but it had not considered that a match of a single

Table 11 *Lead isotope ratios of new Central Taurus ore specimens*

Sample ID	*Laboratory*	*Find site*	*Nature*	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{204}Pb$
Taurus 1A specimens						
TG 237-A	Mainz[1]	Bolkardağ	Copper slag	2.0547	0.8261	0.05261
7	Tokyo[2]	Bolkardağ/Madenköy Ulukişla	Sphalerite	2.0574	0.8271	0.05272
8	Tokyo[2]	Bolkardağ/Madenköy Ulukişla	Gold-containing ores	2.0543	0.8259	0.05261
9	Tokyo[2]	Bolkardağ/Madenköy Ulukişla	Sphalerite/galena	2.0570	0.8269	0.05269
Taurus 1B specimens						
15	Tokyo[2]	Akdağmadeni	Sphalerite/galena	2.0727	0.8351	0.05318
17	Tokyo[2]	Akdağmadeni	Sphalerite/galena	2.0724	0.8348	0.05316
21	Tokyo[2]	Kayseri/Yahyaı Dereköy	Galena	2.0745	0.8366	0.05228
23	Tokyo[2]	Kayseri/Yahyalı Gölgöl	Galena	2.0721	0.8361	0.05318
Pb 85	BNL[3]	Akdağmadeni	Galena	2.0723	0.8352	0.05322
AON243	NIST[4]	Akdağmadeni/Akçakişla Özge Mine	Galena	2.0746	0.8342	0.05312
AON250	NIST[4]	Akdağmadeni/Bayram Ali	Galena	2.0728	0.8337	0.05328
AON256	NIST[4]	Akdağmadeni/Akçakişla	Galena	2.0742	0.8338	0.05329
AON377	NIST[4]	Bolkardağ/Sulucadere	Galena–sphalerite	2.0730	0.8360	0.05313
AON427	NIST[4]	Bolkardağ/Ulukisla Esendemirtepe	Cobaltite/magnetite	2.0726	0.8347	0.0532
Taurus 2A specimens						
1	Tokyo[2]	Aladağ	Smithsonite	2.0788	0.8403	0.05350
2	Tokyo[2]	Aladağ	Sphalerite	2.0805	0.8406	0.05353
3	Tokyo[2]	Aladağ	Zincite(?)/sphalerite	2.0778	0.8395	0.05344
4	Tokyo[2]	Aladağ	Zincite(?)/sphalerite	2.0785	0.8394	0.05344
5	Tokyo[2]	Aladağ	Galena	2.0816	0.8407	0.05352
11	Tokyo[2]	Adana/Etekli Kayadibi	Smithsonite/galena	2.0786	0.8399	0.05344
16	Tokyo[2]	Aladağ/Yahyalı	Galena	2.0781	0.8398	0.05352
18	Tokyo[2]	Aladağ/Yahyalı	Galena	2.0789	0.8400	0.05354
24	Tokyo[2]	Aladağ/Yahyalı Pozantı	Galena	2.0755	0.8383	0.05339
25	Tokyo[2]	Kayseri/Çakılpınar	Galena	2.0789	0.8404	0.05353
Taurus 2B specimens						
TG 237-E3	Mainz[1]	Bolkardağ	Lead Ore	2.0600	0.8291	0.05284
19	Tokyo[2]	Aladağ/Tekneli	Galena	2.0623	0.8307	0.05277
22	Tokyo[2]	Nidğe/Dündarli	Galena	2.0589	0.8284	0.05271
AON126	NIST[4]	Bolkardağ/Sulucadere Üst Mercek	Galena/sphalerite	2.0618	0.8290	0.05285
AON130	NIST[4]	Bolkardağ/Sulucadere Kalay Mer.	Galena/sphalerite	2.0620	0.8291	0.05284
AON378	NIST[4]	Bolkardağ/Sulucadere Kalay Mer.	Galena/sphalerite	2.0633	0.8308	0.05281
AON379	NIST[4]	Bolkardağ/Sulucadere Kalay Mer.	Galena/sphalerite	2.0634	0.8294	0.05281
AON380	NIST[4]	Bolkardağ/Sulucadere Üst Mercek	Galena/stannite	2.0610	0.8291	0.05286
Non-matching specimens						
TG 235-B	Mainz[1]	Pinarbesi/Bogaz	Lead ore	2.0730	0.8400	0.05347
TG 237-G	Mianz[1]	Bolkardağ	Copper ore	2.0733	0.8366	0.05376
6	Tokyo[2]	Aladağ	Smithsonite/sphalerite	2.0759	0.8381	0.05333
20	Tokyo[2]	Ispir (Nidğe-Çarmardı)	Galena	2.0739	0.8402	0.05348
AON581	NIST[4]	Çamardı/Bereketli Maden	Galena/stibnite	2.0822	0.8433	0.05381

[1] Published in Wagner *et al.* (1992).
[2] Published in Hirao *et al.* (1995).
[3] Published in Brill and Wampler (1967): BNL = Brookhaven National Laboratory.
[4] Unpublished data, Specimens collected by K. A. Yener and analysed at the National Institute for Standards and Technology (NIST) by E. C. Joel.

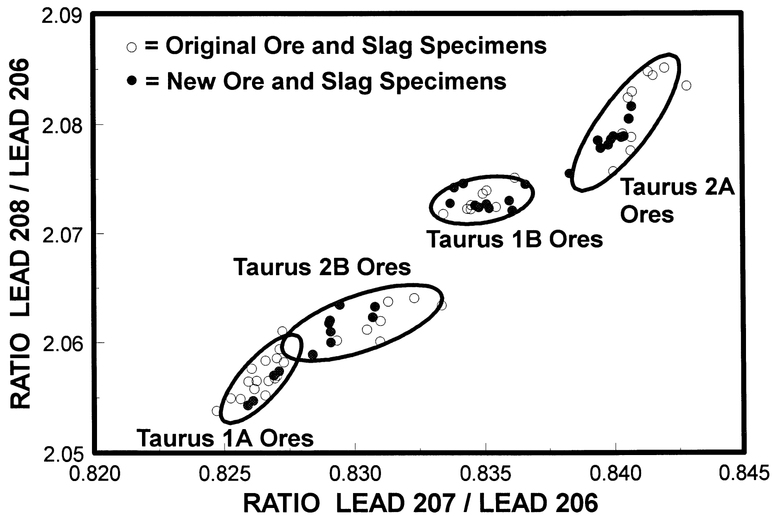

Figure 12 *A stable lead isotope ratio 208/206 versus 207/206 scatter plot of all of the ore specimens presently found to be compatible with the Taurus ore fields. Analogous plots including ratios relative to lead 204 show similar groupings.*

specimen from this site could be weighted too heavily. However, now that an entire group of six specimens from this site have been found to fit the Taurus 1B group exactly, the probability that the two groups relate to each other is strongly indicated. It is geologically reasonable that isotopically matching ores would occur at each of these separate sites, because the Maden Tetkik Arama Genel Müdürlüğü geological map of this region shows that similar granitic to granodioritic intrusions occur in each of the areas at which Taurus 1B specimens have been found. The total extent of the Taurus 1B deposits, about 300 km, although longer than that of the other Central Taurus deposits, is not unusually long for isotopically matching deposits in general. It should be noted that the Taurus 1B deposits all lie along the eastern edge

Table 12 *Compositions of unpublished SI-NIST Central Taurus ores*

Sample	*Concentrations of elements (percentages except for gold)*										
	Lead	*Zinc*	*Copper*	*Iron*	*Arsenic*	*Antimony*	*Cobalt*	*Nickel*	*Tin*	*Silver*	*Gold (ppm)*
Taurus 1B specimens											
AON243	58.0	3.1	0.87	10.30	0.01	0.02	n.d.	0.01	n.d.	n.d.	0.12
AON250	62.0	3.2	0.02	0.55	0.01	0.01	n.d.	0.02	n.d.	0.05	0.13
AON256	56.1	21.1	0.64	3.88	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.09
AON377	42.2	27.8	0.43	5.41	0.21	0.26	n.d.	0.01	0.1	0.01	0.59
AON427	2.2	n.d.	0.47	15.20	13.30	n.d.	9.1	0.03	0.02	0.02	1031.00
Taurus 2B specimens											
AON126	5.4	35.6	1.13	7.10	0.32	0.02	n.d.	0.01	0.24	0.03	2.29
AON130	17.4	9.8	0.54	8.48	0.53	0.51	n.d.	n.d.	0.16	0.04	10.10
AON378	14.7	23.7	0.33	9.37	0.16	0.06	n.d.	n.d.	0.33	0.08	0.88
AON379	42.2	27.8	0.43	5.41	0.21	0.26	n.d.	0.01	0.10	0.01	0.59
AON380	55.6	14.2	0.61	8.70	0.78	0.32	n.d.	0.01	0.13	0.02	1.79
Non-matching specimen											
AON581	2.8	0.04	0.04	0.51	0.47	15.50	n.d.	n.d.	n.d.	n.d.	4.57

n.d., Not detected.

of the Anatolian Plate (for the location of this plate, see Wagner *et al.* (1992), Figure 2). It also should be noted that all of the new Taurus 1B specimens contain significant amounts of lead, the average of the lead determinations for our five new specimens, individually listed in Table 12, being 44% and all of the other specimens being described as either galena or sphalerite/galena.

The new Taurus 2A specimens all came from the same Aladağ and Yahyalı sites as the original specimens, except for No. 25, which came from the slightly more northern site of Kayseri/Çakılpınar. Two of the new Taurus 2B specimens came from the sites Yahyalı/Tekneli and Niğde, from which some of the original Taurus 2B specimens were derived but, unexpectedly, the remaining six all came from the Bolkardağ valley. One of these specimens, TG 237-E3, was published by Wagner *et al.* (1992), but the remaining five had been selected for analysis at NIST because they came from the same locale from which a Taurus 1B specimen, AON116, had been taken. It is not too surprising, however, that the Taurus 2B deposits, like the Taurus 1B, also extended down into the Bolkardağ valley. One fairly frequently encounters instances in which ores with significantly different isotope ratio signatures, such as Taurus 1B and Taurus 2B, are found at common sites, the side-by-side occurrence of North Central Anatolia and Trabzon ores being a notable example.

Catalogue of new Central Taurus ore specimens analysed at NIST

New Taurus 1B Specimens

AON243	Sivas/Akdağmadeni, Akçakğışla. Galena sample taken from ore heap from Özge mine. Modern mine cuts through small ancient workings.
AON 250	Sivas/Akdağmadeni, Bayram Ali. Galena sample taken from a modern mine. Site of Çiçekli Tepe nearby has collapsed vertical pits, ancient mining works.
AON256	Sivas/Akdağmadeni, East of Akçakışla, Büyük Güney Tepe,. Galena sample taken from modern mine.
AON427	Bolkardağ/Ulukışla, Esendemir Tepe. Cobaltite with some magnetite.

New Taurus 2B Specimens

AON126	Bolkardağ/ Sulucadere. Galena–sphalerite sample containing stannite removed from the upper outcropping vein.
AON130	Bolkardağ/ Sulucadere. Galena–sphalerite sample containing stannite removed from the outcropping vein.
AON378	Bolkardağ/Sulucadere. Galena–sphalerite sample containing stannite removed from the outcropping vein.
AON379	Bolkardağ/Sulucadere. Galena–sphalerite sample containing stannite removed from the outcropping vein.
AON380	Bolkardağ/ Sulucadere. Galena-sphalerite sample containing stannite removed from the upper outcropping vein.

Non-matching Specimen

AON581	Çamardı/Bereketli Maden. Galena–stibnite sample collected from the remains of ancient workings.