Lead Isotopes in Ancient Coins

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IN previous publications we have reported the results of investigations of isotope ratios of lead extracted from various ancient materials.[1] These publications have established the usefulness of such ratios for classifying the objects according to the types of lead they contain and for identifying the possible geographical sources of the leads. Since details of the reasoning behind these investigations and those of the capabilities and limitations have already been thoroughly discussed, we shall comment here only as briefly as necessary on these topics, before moving on to the main topic of this paper, our investigation of isotope ratios of lead extracted from ancient bronze, silver, and gold coins.

Galena ores (lead sulphide) from deposits of different geological settings often vary in their isotopic composition, that is, in the relative proportions they contain of the four stable isotopes of lead, Pb^{204}, Pb^{206}, Pb^{207}, and Pb^{208}. By determining the isotopic compositions of samples of lead removed from ancient objects, and comparing them to the compositions of ores, it becomes possible to tell from which mining regions the leads in those objects could possibly have come—and from which regions they could not have come. We have so far studied samples of lead from about 300 ancient objects, and the results have confirmed that these studies offer valuable evidence concerning the provenances of these objects. The two most noteworthy characteristics of this method, viewed as an archaeometric tool, are its versatility in regard to the materials to which it can be applied, and its relative insensitivity to the chemical histories of the objects studied. Among the materials analysed are metallic leads, corrosion products, and lead extracted from such diverse materials as glasses, glazes, white lead pigments, leaded bronzes, silvers, and golds. Since the isotopic composition of lead is relatively unaffected by the chemical and physical processes to which it is ordinarily subjected in its conversion from an ore to an artifact—and by subsequent burial and passage of time—the isotopic ratios determined today for samples removed from ancient objects are identical (or very nearly so) to those of the ores from which the leads were originally smelted.

Fortunately, the question of sampling, which is so often a major concern in archaeometric studies, does not ordinarily pose problems in lead isotope investigations. The sample sizes required have now become so minute that the quantities of material which

[1] R. H. Brill and J. M. Wampler, 'Isotope studies of ancient lead', *AJA* LXXI (1967), 63–77; id., 'Isotope ratios in archaeological objects of lead', *Application of Science in Examination of Works of Art* (W. J. Young, ed.), Boston, 1967, 155–66; R. H. Brill, 'Lead isotopes in ancient glass', *Annales du 4e Congrès des Journées Internationales du Verre* (International Association for the History of Glass), Liège, 1969, 255–61; id., 'Lead and oxygen isotopes in ancient objects', *The Impact of the Natural Sciences on Archaeology* (ed. T. E. Allibone *et al.*), London, 1970, pp. 143–64. (The same paper also appears in *Phil. Trans. Roy. Soc. Lond.* A. 269 (1970), 143–64); R. H. Brill, W. R. Shields, and J. M. Wampler, 'New directions in lead isotope research', *Application of Science in Examination of Works of Art* (W. J. Young, ed.), Boston, 1971 (in press).

must be sacrificed are usually inconsequential if one considers the valuable information that can be obtained from them.[1] The one situation where sampling does pose problems is when one is working with alloys or other materials having low lead contents, for example, with silver and gold objects, which may contain only traces of lead. However, more troublesome difficulties stem from two sources of ambiguity which are not of an experimental nature, but are inherent in the logic behind the interpretation of the data. The first is that although each individual lead deposit is characterized by a particular isotopic composition, these compositions are not often unique to a given deposit. Leads coming from widely distant mining regions may, if they are from similar geological settings, be indistinguishable from one another isotopically. Some of our most recent data, however, show promise that high-accuracy determinations may alleviate a good deal of this source of ambiguity by allowing one to see fine systematic variations among leads which previously had to be regarded as indistinguishable. The second difficulty arises from the fact that in the ancient world, as today, scrap metals were salvaged and melted down together to be used again. When leads with different isotopic compositions are mixed together, the resulting mixtures have compositions somewhere intermediate between the starting values. Neither of these sources of ambiguity are really anything new. Both have close parallels in the treatments of other types of archaeometric data. Although they must always be borne in mind when interpretations are drawn, they do not to any drastic extent diminish the usefulness of lead isotope studies.

Fig. 1 illustrates the range of isotope values that have been determined previously for samples of all types of archaeological materials that we have studied. These data tend to gather into a few separate groups containing leads with similar isotopic makeups. For convenience these were labelled L, E, and S because they contained, respectively, leads known to have originated in Laurion, England, and Spain. An intermediate, and somewhat diffuse isotopic type, 'Group X', contains leads from many objects excavated in Italy and in the Levant.

In this investigation we have studied lead extracted from fifty-five samples removed from bronze coins or, in some cases, lead recovered from gravimetric chemical analyses. The coins were all known, on the basis of previous chemical analyses carried out by the donors, to contain substantial proportions of lead—proportions sufficient in most cases to be regarded as resulting from intentional additions of lead. The coins were provided by Professor Earle R. Caley and Mr. Lawrence H. Cope, to both of whom we are very much indebted for their generosity and continuing co-operation. These groups of coins were ideal for starting this survey, not only because they were already known to contain lead, but also because they had already been sampled. Therefore, there was no need to damage otherwise perfect coins for our exploratory survey. The coins studied contain from

[1] Using new techniques of high-accuracy mass spectrometry developed at the National Bureau of Standards, it is possible to obtain acceptable results on samples containing as little as 1 μg. of lead, although somewhat larger samples, weighing of the order of a few milligrams, are more convenient to work with and yield more accurate results. Accuracies of 0·05 to 0·10 per cent in the ratios reported here are routinely obtained on the larger samples. For materials having low lead contents the samples sacrificed must be sufficient to contribute the required minimum of 1 μg. of lead. Where the lead content is as low as 0·1 per cent the weight of gold, silver, or alloy which must be consumed is about 1 mg. This corresponds to a volume about that of a cube of metal measuring 0·5 mm. on an edge.

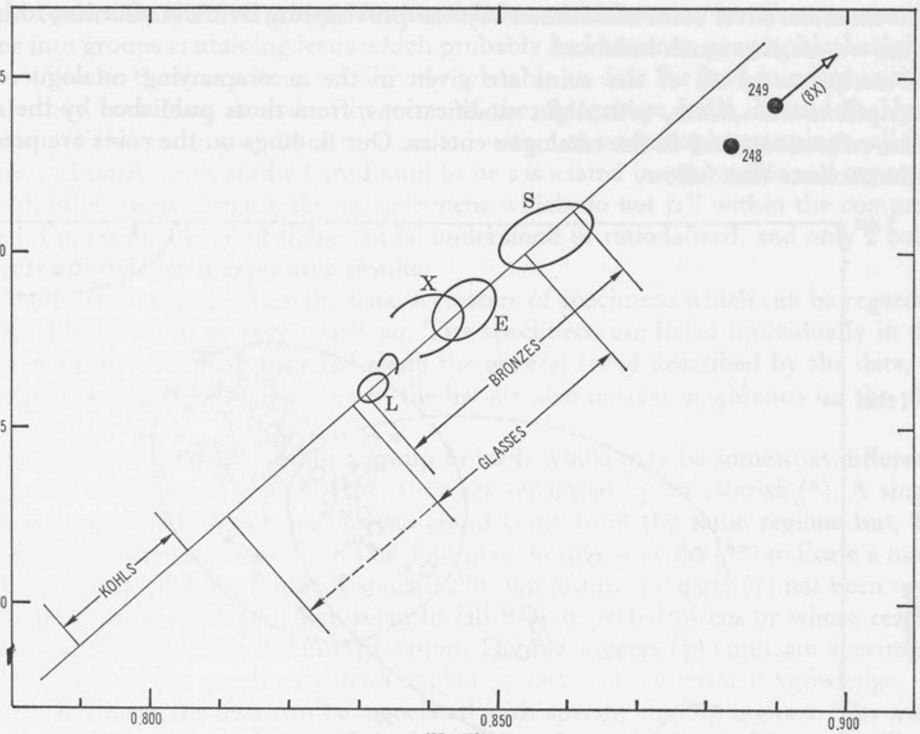

FIG. 1. Isotope ratios of lead extracted from various ancient materials. The groups and ranges were compiled from about 300 samples. More than 90 per cent of all samples fall within the range marked 'Bronzes'. The point for sample 249 falls off the graph to the right at a distance of eight times the length of the vector. The diagonal is a reference line showing the general trend of the data.

0·7 to 37 per cent lead and range in date from *c.* 330 B.C. to *c.* A.D. 300. The specimens provided by Professor Caley[1] are mostly of Greek and Roman types, whereas Mr. Cope's are all Roman coins,[2] most of which were struck in about A.D. 300. In addition, we have studied one lead coin from India[3] submitted by Professor K. T. M. Hegde and

[1] E. R. Caley, 'The composition of ancient Greek bronze coins', *Memoirs of the American Philosophical Society* XI (1939); id., *Orichalcum and Related Ancient Alloys* (*NNM* CLI), New York, 1964.

[2] L. H. Cope and H. N. Billingham, 'The composition of 35 Roman bronze coins of the period A.D. 284–363', *Bulletin of the Historical Metallurgy Group* I (1967), no. 9, 1–6; id., 'The composition of 26 Roman Imperial silver and bronze coins minted between A.D. 206 and 360', ibid. II (1968), 51–3 (cited as Cope and Billingham, 1968*a*); id., 'Chemical analyses of 31 large Roman bronze coins minted between A.D. 294 and 307', ibid. II (1968), 70–2 (cited as Cope and Billingham, 1968*b*); id., 'Chemical analyses of some weight-reduced Roman folles minted between A.D. 307 and 318', ibid., III (1969), 30–2; id., 'The chemical composition of the bronze coinage of Maxentius, A.D. 306–312', ibid. III (1969), 62–4; id., ibid. V (1971) (in press); L. H. Cope, 'The argentiferous bronze alloys of the large tetrarchic folles of A.D. 294–307', *NC* 7. VIII (1968), 115–49, at 124 f.; id., 'The metallurgical analysis of Roman imperial silver and *aes* coinage', above, pp. 3–47.

[3] K. T. M. Hegde, 'Source of the metal in the lead coins of the Kshatrapa period', *Current Science* XXXVII (1968), 518–20.

a few Sasanian silver coins and related objects[1] provided by Dr. A. A. Gordus, to both of whom we are also much indebted.

Descriptions of all of the coins are given in the accompanying catalogue. These descriptions were taken, with slight modifications, from those published by the donors in the references cited in the catalogue entries. Our findings on the coins are presented in the sections that follow.

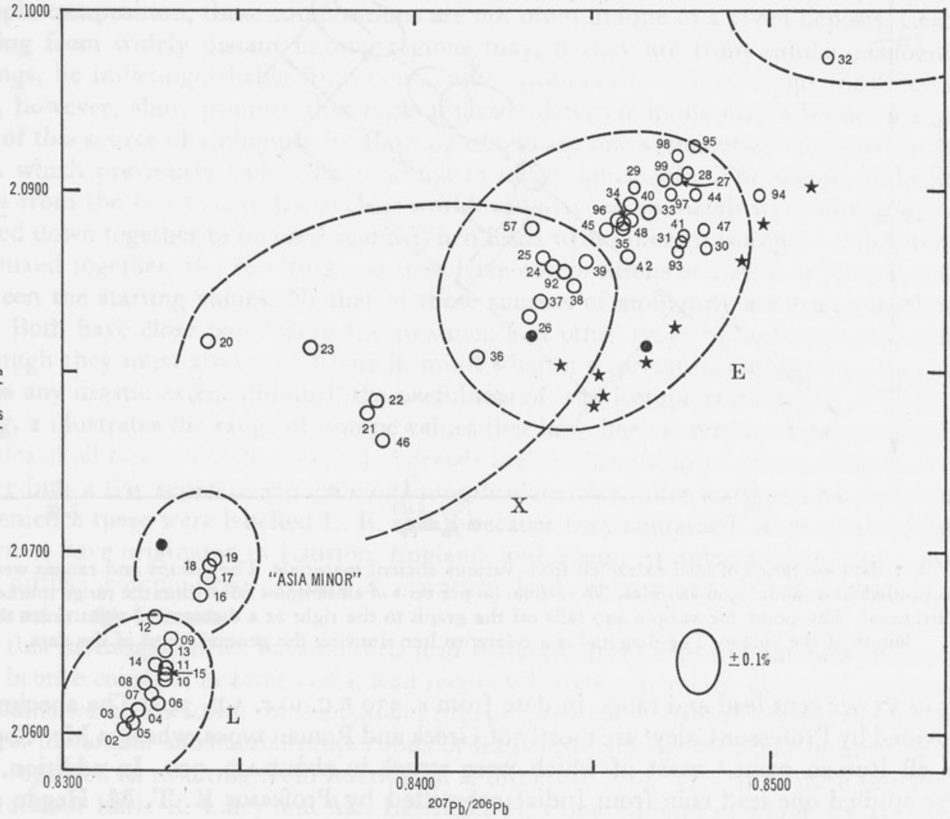

FIG. 2. Isotope ratios of lead extracted from Greek and Roman bronze coins. Samples are identified by the last two digits of their catalogue numbers. The stars represent samples from a group of lead pigs of Romano-British origin and the closed circles are a few ores plotted for future reference. Note change of scale from Fig. 1.

GREEK AND ROMAN BRONZE COINS

The data on the Greek and Roman coins are tabulated in **Table I** (see p. 302) and plotted in **Fig. 2**. From a consideration of these data the coins were divided, on a purely

[1] A. A. Gordus, 'Neutron activation analysis of coins and coin streaks', above, pp. 127–48; id., 'Rapid nondestructive activation analysis of silver in coins', *Science and Archaeology* (R. H. Brill, ed.), Cambridge, Mass., 1971, pp. 145–55; id., 'Neutron activation analysis of streaks from coins and metallic works of art', *Application of Science in Examination of Works of Art* (W. J. Young, ed.), Boston, 1971 (in press).

empirical basis, into the five groups discussed below, which serve, in effect, to classify the coins into groups containing leads which probably had common geographical origins. In order to make these results more directly relatable to data for lead in other ancient materials they have been described in terms of the old groups L, X, E, and S. Upon comparison of the mints and dates represented within these isotopic groupings, all but 12 of the 55 bronze coins studied are found to be associated in reasonable and expected ways with other coins. Among the 12 specimens which do not fall within the company expected, the results for 10 of these can be understood or rationalized, and only 2 coins show truly spurious or inexplicable results.

The leads are arranged within the lists as clusters of specimens which can be regarded as isotopically identical or very nearly so. The specimens are listed individually in the approximate order in which they fall along the general trend described by the data, so that the points closest to one another in the list are also nearest neighbours on the plot itself.

Where a transition occurs within a group to leads which may be somewhat different, although still of the same general type, they are separated by an asterisk (*). A single asterisk separates leads which we suspect could come from the same regions but, for example, from different contact levels or deposits. Double asterisks (**) indicate a more distinct separation, and one which is statistically significant. A dagger (†) has been used to designate those specimens which seem to fall in unexpected places or whose results require some special efforts for interpretation. Double daggers (††) indicate specimens whose positions on the graph we cannot explain in terms of our present knowledge.

In some instances the data can be associated with specific mining regions. The most definite connection that can be established is that involving the data in Group L. These leads (with the possible exception of 609, 612, and 613) come from coins whose mints and dates indicate that they actually do contain Laurion lead. All of the other data are best regarded as groups of leads which we expect to have had common geographical origins, according to the clustering of the points on the graph, although the particular locations of the mines must remain unspecified for the time being. As our catalogue of isotope data on ores from ancient mining regions becomes more comprehensive, we expect it will become possible to identify at least some of these locations. Because of time limitations, we have not yet completed our attempts to compare our classification of the coins with those based on the chemical analyses carried out by the donors of the coins.

Type L

602—Egypt or Cyprus, 146–127 B.C.
603—Same.
605—Athens, 307–261 B.C.
604—Alexandria, 169–146 B.C.
* (?)
606—Athens, second century B.C.
607—Athens, *c.* 88 B.C.
608—Athens, mid-second century B.C.
* (?)

610—Athens, 330–307 B.C.
611—Same.
††615—Apameia, 133–48 B.C.
†614—Syria, 187–175 B.C.
†613—Rome, *c.* 159 B.C.
609—Athens, first century B.C.
* (?)
†612—Laconia, 146–32 B.C.

Most of these leads of Type L probably are actually Laurion lead. This is certainly true for the Athenian coins (with the possible exception of 609 which, it will be noted, is also of a rather late date). The other coins come mostly from sources where local lead is not readily available and/or date from periods when Laurion lead can reasonably be expected to have been in use. Those from Egypt, Syria, and Rome are generally earlier in date than other coins from the same localities which contain lead of Types X and E. Only 615, a coin from Apameia, seems to raise a serious question. An identical coin, 616, contains a different type of lead which falls in the 'Asia Minor' group described next and we are at a loss to explain why these two coins do not contain the same type of lead. Sample 612 is somewhat different from the rest of the leads of Type L. It lies just on the border line of the group and deviates in the direction of leads found in two early bronze objects not reported here (one Etruscan and one Cypriot), and could conceivably be related to them, but additional data are required before a definite connection could be established.

'Asia Minor' (?)

616—Apameia, 133–48 B.C.
617—Sardis, A.D. 14–38.
618—Antioch, first century B.C.
†619—Athens, 27 B.C.–A.D. 14.

These specimens are all very much like one another, and differ significantly from both the Type L and Type X leads which bracket them. They represent a recognizable isotopic type of lead which we believe comes from Asia Minor and perhaps elsewhere as well. The evidence for localizing the lead from these four specimens so specifically is as yet slim, but in addition to these points, we have also analysed an ore from Balya, near Balikesir in Turkey, which resembles them.[1] Further data on leads and ores from this region should be of help in proving or disproving the reality of a distinct 'Asia Minor' type.

Type X (and overlapping Type E)

620—Syria, 121 B.C.
623—Syria, 114 B.C.
*
622—Alexandria, A.D. 117–38.

[1] R. H. Brill, W. R. Shields, and J. M. Wampler, 'New directions in lead isotope research', op. cit. (1971).

621—Rome (?), A.D. 208.
646—Constantinople, A.D. 393–5.
**
636—Heraclea, A.D. 351–4.
*
626—Antioch, A.D. 244–9.
637—Antioch, A.D. 299–300.
* (?)
638—Alexandria, A.D. 302–3.
692—Heraclea, A.D. 378–83.
624—Phoenicia/Syria, 146–138 B.C.
625—Antioch, A.D. 98–117.
639—Alexandria, early A.D. 311.
* (?)
657—Beth She'arim, probably Roman Imperial.
** (?) With respect to the next group.

The isotopic range covered by this group of fourteen coins is quite broad. We have chosen to list them together because this same range of values includes many specimens of leads from other types of ancient materials excavated in the same area where these coins were minted. These other specimens, run earlier, constitute the Type X lead. Most of them came either from Italy or from what we might best describe as the Levant. For various reasons it does not seem likely that the Italian and Levantine leads came from the same mining regions, but that instead this is an example of the overlapping alluded to earlier. Two different mining regions supplying these two different parts of the ancient world just happen, by geological coincidence, to contain leads of similar isotopic compositions. Restricting ourselves to the Levantine specimens, we must assume, in order to account for the spread in the data, that a few different deposits contributed to this lead. It cannot now be decided whether these deposits were far removed from one another or whether they were mines near by one another which contain different types of lead. The leads in this group came mainly from sites ringing the eastern end of the Mediterranean from Alexandria around the southern coast of Turkey. A few of them were found in Constantinople. Lead of this type must have travelled readily throughout this region in a sort of 'plumbeous crescent'. Since it was undoubtedly salvaged occasionally for reuse, mixing must have sometimes occurred. Possibly some of the coins discussed here contain mixed leads.

Among the nineteen coins we have studied which were minted within the region covered by Type X, only six fall into other isotopic groups. These tend to be the earlier coins and four of the six are in Type L. The correlation is not perfect but the suggestion seems to be that leads excavated in the region in question, or the lead in bronze coins minted there, are ordinarily of Type X, except for some of the earlier examples which contain Laurion lead, or which deviate in the direction of Type L leads.

The possibility also remains that some of the coins in this group could contain lead from Italy. An obvious example is 621, thought to have been minted in Rome, but there could be others as well.

Type E

** (?) With respect to the preceding group.

645—Ostia, A.D. 308.
635—Siscia, A.D. 295.
634—Milan, *c*. A.D. 272–4.
696—Rome, A.D. 266–8.
648—Rome, A.D. 195–6.
633—Rome, *c*. A.D. 299.
†640—Lyons, *c*. A.D. 298.
629—Rome, A.D. 189.
†642—Trier, A.D. 300–1. (Classification doubtful.)

* (?)

697—Rome, A.D. 118.
†627—Alexandria, *c*. A.D. 111.
699—Rome, A.D. 253–9.
628—Rome, A.D. 171–2.
698—Rome, A.D. 183–4.
†695—Britain, third century A.D.

* (?)

644—Rome, A.D. 309–10.

**

693—London, *c*. A.D. 300.
631—London, A.D. 306–7.
†641—Lyons, A.D. 295.
647—London, A.D. 296.
630—London, A.D. 300.

**

††694—Rome, A.D. 64–8.

Within Type E there are two distinctly different isotopic types of lead. The first fifteen specimens listed (645–95) consist primarily of coins from Rome and northern Italy or the east coast of the Adriatic. It is difficult to decide if these are all one type of lead or if they should perhaps be subdivided into two very similar subgroups. In any event, it seems likely that they came from either one or two mining regions supplying lead to Rome and northern Italy during this period. There is a pronounced tendency for the leads in the earlier coins to fall in the cluster on the right, while those from the later coins fall in the cluster to the left. Additional analyses should prove whether or not this distinction is real. It should also be pointed out that another body of data on Italian leads of later periods[1] (white lead pigments, Renaissance bronzes, and one ore from Tuscany) are in the same part of this graph but further up to the right. These are definitely believed to be from native Italian ores but are clearly different from the leads seen in the Roman bronze coins we have been discussing.

[1] R. H. Brill, W. R. Shields, and J. M. Wampler, 'New directions in lead isotope research', op. cit. (1971).

The second type of lead showing up in Group E consists of four coins minted in London and one minted in Lyons. Before having collected much high-accuracy data on British leads it was thought that these were probably leads mined locally in Britain.[1] However, having now completed high-accuracy determinations on a suite of nine samples removed from Roman lead pigs found at various places in Britain it is beginning to seem doubtful that the lead in these coins could have come from a native British ore. The nine pigs stretch out in a trend falling significantly below the coins minted in London. It is possible, of course, that we simply have not yet analysed the proper ores or pigs which would establish that the lead in these coins is of local origin. As our survey of British leads continues this question may be cleared up, or perhaps alternative matching ores will be found elsewhere.

The result for sample 695, from a coin thought to be a British forgery of a dupondius, is interesting because the lead in it looks more like those found in coins struck in Rome than like those struck in Britain. Perhaps numismatic arguments can resolve the apparent anomaly. For example, the coin might have been struck in metal from a coin of the earlier period minted in or near Rome.

The results for 642 and 694 pose some problems. The lead in 642, which was struck in Trier, looks more like those found in the coins struck in Rome than anything else, but it is not a close match. The lead in 694, struck in Rome in A.D. 64–8, does not closely resemble any of the other leads discussed above, but it is not unlike that in a British lead pig found in Flint; nor is it very different from the group of later Italian leads mentioned earlier. Interpretations of these two specimens should be reserved until additional data are available.

Type S

†632—Rome, A.D. 307.

Only one specimen was found which contains a lead of Type S, the group known to contain leads from Spain and some other sources. This coin is an oddity in itself, since Mr. Cope suspects that it was a contemporaneous forgery. The lead in this coin also resembles that which we have mentioned earlier as having been found in the later Italian objects.

SILVER COINS

In ancient times silver was commonly obtained through cupellation, a process by which it was chemically extracted from lead. Since this separation and subsequent refining processes could rarely have been completely efficient, most specimens of ancient silver must contain some traces of their parent lead. Thus, by determining isotope ratios of any lead remaining in silver objects it should be possible to classify ancient silvers according to their geographical origins, just as is done with the leads. One complication to be anticipated at the outset is that the mixing problem might be more serious with lead

[1] R. H. Brill, 'Lead and oxygen isotopes in ancient objects', op. cit. (1971).

extracted from silvers than with leads themselves. Whereas lead *per se* was not inherently valuable in the ancient world, and might have been discarded from time to time, it is doubtful that silver, except under the most unusual circumstances, would ever have been intentionally discarded. Instead it was hoarded, passed from hand to hand, and eventually might have been remelted, thereby often finding its way into other objects or coins. As a consequence, silvers from different sources, or silvers mined several centuries apart, could easily have become mixed together.

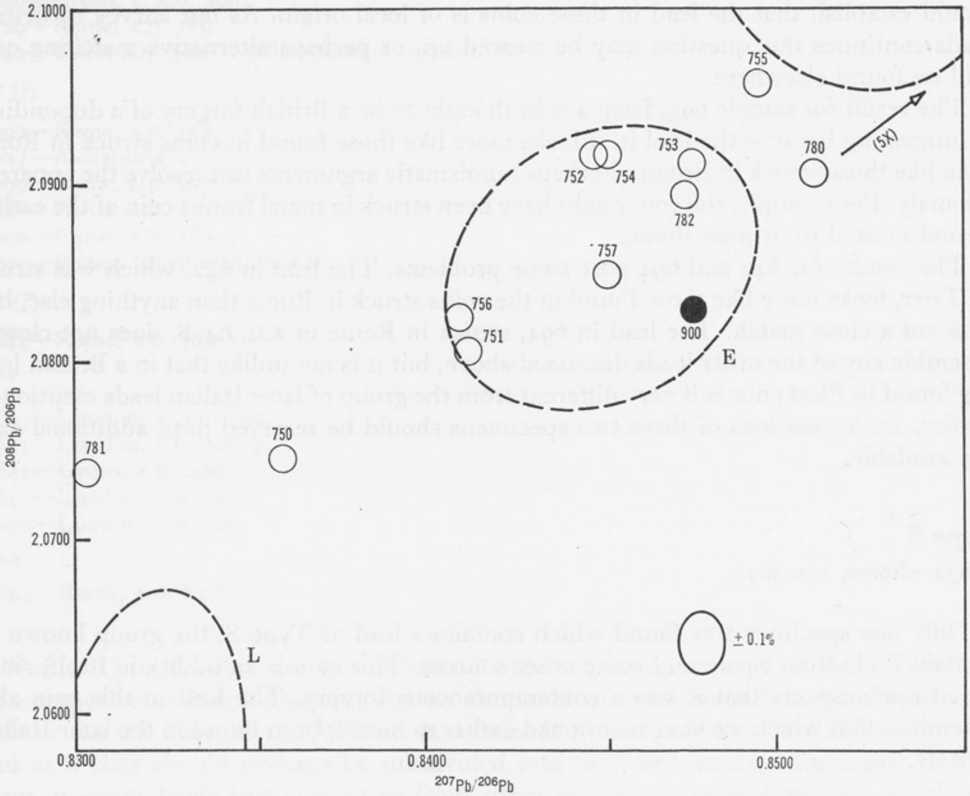

FIG. 3. Isotope ratios of lead extracted from some ancient silvers and from one gold coin.

Our first efforts with ancient silvers were carried out on a group of eight silver coins provided by Dr. Gordus, along with three pieces of silver removed from larger objects.[1] The data are given in Table I and are plotted in Fig. 3. At this early stage and with so few results it is difficult to assess the situation, so only a few comments can now be made.

[1] A. A. Gordus, 'Neutron activation analysis of coins and coin streaks', above, pp. 127–48; id., 'Rapid nondestructive activation analysis of silver in coins', *Science and Archaeology* (R. H. Brill, ed.), Cambridge, Mass., 1971, pp. 145–55; id., 'Neutron activation analysis of streaks from coins and metallic works of art', *Application of Science in Examination of Works of Art* (W. J. Young, ed.), Boston, 1971 (in press).

The data on the Sasanian specimens show a decided spread but it is interesting to note that among these there are close coincidences between some pairs of points, for example, between 752 and 754 and between 751 and 756. The observed spread indicates that the silvers were extracted from leads which came from different deposits, although some mixing may also have been introduced. It will be seen that the lead in an Umayyad silver coin minted in Damascus (757) falls close to the lead extracted from bronze coins of a much earlier date which were minted in or near Syria. Several samples of leads from different ancient materials (metallic leads and glasses) also excavated in that region have isotope compositions similar to that of this specimen. There must have been a long-standing exploitation of one particular lead deposit by metallurgists of that region. Two samples of Parthian origin (750 and 781) are similar to one another in the ratios usually reported and are especially interesting in that both appear to have significantly higher Pb^{204} contents (with respect to Pb^{206} and Pb^{207}) than we have seen in the large majority of our previous data. Therefore, it seems quite likely that the lead in these two silver specimens came from a source of galena ore which might some day be identified, and that the relatively rich Pb^{204} contents might serve to characterize one type of silver in use in the ancient world.

Among the other points plotted are leads from three Sasanian silver objects which are not coins. We have plotted these points for future reference and as illustrations that lead isotope data may offer important clues for locating the origins of such objects as well as judging their authenticities. It would be premature, however, to comment upon the authenticity of these objects before additional comparative data are available.

GOLD COINS

The possibility of classifying early gold objects on the basis of the isotopic compositions of their trace contents of lead also looks promising, but the picture is a little different from that involving the silvers. While chemical analyses of ancient golds are not very common it does seem that at least some golds contain appreciable proportions of lead. What is not quite clear, however, as it is with the silvers, is how that lead has come to be in the gold. The lead may be a natural accompanying trace occurrence, or it may have been introduced by metallurgical processing, or both. One might anticipate, too, that the mixing problem could be serious with gold, because of its great inherent value. On the other hand, it is possible that the sources of gold, especially in earliest times, were limited and there may be fewer isotopic types of lead to be dealt with. In any event, it seems very worthwhile to make some exploratory analyses.

At present only one gold sample (900) has been studied. This was a light filing from the perimeter of a Byzantine coin, a nomisma of John II Comnenus (1118–43). We are very grateful to Mr. Timothy Boatswain who lent this coin for analysis. The data for the sample are listed in Table I and plotted in **Fig. 3**. This point falls in Type E along the trend of the British pigs mentioned above. It is also an almost perfect match for a sample of lead coming from a stained-glass window in Heiligenkreuz dating from *c.* 1295. The match is probably only coincidental, because gold from many sources was undoubtedly in circulation in the Byzantine world, and it probably contained lead of various isotopic compositions. However, to demonstrate the lines of reasoning that one is inevitably drawn into, we might point out that there are several lead-producing regions located not far from Heiligenkreuz and at least one of these, the Tauern range, was also a gold field known in Roman times. Thus it is conceivable that gold from one of these regions could have reached the Byzantine world during the Middle Ages (or earlier) and that these two objects, which are of such incongruous types, actually could contain metals having a common origin. Before a proper interpretation of the findings on this coin can be made, we must look further into the isotopic composition of lead in ancient golds and in ores from gold-producing regions. Therefore any help that can be provided in obtaining additional samples of gold for continuing these explorations would be very much appreciated.

A LEAD COIN FROM INDIA

Professor K. T. M. Hegde has submitted for study an early lead coin from India[1] along with a sample of galena ore. The coin was excavated at Nagara in the Kaira District and dates from the Kshatrapa Period (*c.* A.D. 100–400). The ore is from Zawar, which is about 180 miles north of Nagara, and is a likely source for the lead used in making the coin. On the basis of spectrographic chemical analyses of coins of this type and of the ore, Professor Hegde proposed, quite reasonably, that the lead in the coins could have come from this ore deposit. Isotope determinations on both samples show that both are of roughly similar isotopic compositions in that they fall well off to the right of the data plotted for the other specimens in this study. In order to plot the data on the same graph as our other determinations, the scale has to be expanded, as it is in **Fig. 1**, where the two Indian samples are plotted (248 and 249). (Even so, 249 still falls off the graph as indicated by the small vector.) On the basis of what is known about Indian ores, the two samples would be expected to have isotopic compositions of the sort determined. However, the difference between the two specimens is clearly sufficient to conclude that the lead used for making the particular coin we have studied did not come from the same deposit as the ore specimen analysed. We plan to continue our study of leads from India since they are of recognizable isotopic types and hope that data on additional coin specimens may be associated more closely with some other known ore deposits.

SUMMARY AND FUTURE PROSPECTS

It has probably become clear to the reader that in this research we are still going through a stage wherein every sample run not only teaches us something new but may also have a bearing on the interpretation of previous data, occasionally in some quite unexpected way. Just as in so many other archaeometric undertakings, the new facts we learn on a day-to-day basis sometimes clarify an over-all picture—and sometimes tend to complicate it, but all considered, the prevailing outlook in this research is now definitely one of clarification.

For the archaeologist and historian, lead isotope studies are firmly established as a source of evidence on the provenance of excavated objects, and the initial results on coins

[1] K. T. M. Hegde, op. cit.

described here imply to us that the same benefits are now available to the numismatist. The specimens looked at so far were ideal for surveying the situation and for evaluating the extent of variability that exists among leaded bronze coins. Now it is desirable to proceed beyond this survey to still another level of research, namely, the study of coins selected with a view towards answering questions explicitly formulated by numismatists. It is only with the help of numismatists that future experiments can be designed so as to make the best use of this technique and to obtain information which is of the sort most needed. Therefore, we welcome further donations of samples for analysis and suggestions related to problems which might be resolved by isotopic investigations. Concerning sampling, we might remind the curator, who is understandably hesitant, that the quantities of metal required are very small and that the samples to be analysed need not necessarily be taken from the finest examples of the coin types to be studied. From the experimental point of view, data on badly worn coins are just as valid as those on the finest specimens. In addition, we remind the chemical analyst that isotopic determinations can be carried out on the residues of samples recovered from gravimetric chemical analyses or aliquot solutions.

The investigation of silver and gold coins will be especially emphasized in the future. Several Parthian and Sasanian coins are now being analysed, and we hope to solicit examples of Greek silver coins for an attempt at distinguishing between silver from the Laurion mines and that from Macedonia or other sources within the reach of the Greek world. The choice of other lines of research to be emphasized will be largely dependent upon the responses of numismatists concerning the types of information they would like most to have.[1]

CATALOGUE OF SAMPLES

Greek and Roman bronze coins

Samples Pb-602 through Pb-629 were removed from coins provided by Professor Earle R. Caley who had previously analysed them. The descriptions which follow were taken (with minor changes) from those accompanying Professor Caley's published analyses. See p. 281 n. 1.

The samples numbered between Pb-630 and Pb-699 (with the exception of Pb-657) were provided by Mr. Lawrence H. Cope, who had previously analysed most of them. These analyses, carried out with Mr. H. N. Billingham, are published in references 8–15. The descriptions given here were furnished by Mr. Cope, who dated and identified the coins in collaboration with Mr. R. A. G. Carson of the British Museum. See p. 281 n. 2.

In dating entries a date in bold type within a range indicates that preferred by the donor. Abbreviations for references cited in catalogue entries are as follows: *Svoronos*—J. N. Svoronos, *Trésor des Monnaies D'Athènes*, Munich, 1923–6; *B.M.C.—A Catalogue of Greek Coins in the British Museum*; *R.I.C.—The Roman Imperial Coinage*; *L.R.B.C.—Late Roman Bronze Coinage.*

[1] *Acknowledgements.* The analyses reported here were performed at the National Bureau of Standards by I. L. Barnes, T. J. Murphy, and co-workers of the Analytical Mass Spectrometry Section, and by J. M. Wampler, Georgia Institute of Technology, while a guest worker at the Bureau.

Pb-602 Coin of Ptolemy VIII. Struck in (or for) Cyprus; 146–127 B.C.
Obv. Head of Cleopatra I r., as Isis, with long curls, bound with grain.
Rev. ΠΤΟΛΕΜΑΙΟΥ ΒΑΣΙΛΕΩΣ
Eagle l. on thunderbolt, wings open; to l., monogram of the mint of Paphos.
Wt. = 16·4 g. Size = 27×4 mm. Soft, slightly corroded metal.
Ref. Caley (1939), p. 98, no. 6. See also *B.M.C. Ptolemies*, Plate XXI, no. 3.
Pb content 24·0 per cent.

Pb-603 Coin of Ptolemy VIII. Struck in (or for) Cyprus; 146–127 B.C.
Same type coin as Pb-602.
Wt. = 15·0 g. Size = 25×4 mm. Soft, slightly corroded metal.
Ref. Caley (1939), p. 98, no. 7.
Pb content 36·8 per cent.

Pb-604 Coin of Ptolemy VI. Probably Alexandria; 169–146 B.C.
Obv. Head of Zeus to r.: border of dots.
Rev. ΠΤΟΛΕΜΑΙΟΥ ΒΑΣΙΛΕΩΣ
Two eagles to l., on thunderbolt: border of dots.
Wt. = 23·2 g. Size = 30×4 mm. Brittle metal heavily corroded on the surface.
Ref. Caley (1939), p. 98, no. 5.
Pb content 28·8 per cent.

Pb-605 Coin of Athens. 307–283 B.C. or **283–261** B.C.
Obv. Head of Athena r., wearing crested Corinthian helmet.
Rev. A / Θ E (Triangular arrangement around head.) Owl r., head facing. In field r., symbol, wreath.
Wt. = 1·9 g. Size = 14·5×2·1 mm. Moderately hard, brittle metal with reddish-brown fracture. Much internal corrosion.
Ref. Caley (1939), p. 31, no. 11. See also *Svoronos*, Plate 22, nos. 76, 77.
Pb content 3·2 per cent.

Pb-606 Coin of Athens, New Style. Second century B.C.
Obv. Head of Athena Parthenos r.
Rev. A ΘE Owl r., on prostrate amphora; head facing, wings closed; no symbol in field.
Wt. = 8·3 g. Size = 20×4 mm. Moderately hard, rather brittle, sound metal with reddish-grey fracture.
Ref. Caley (1939), p. 41, no. 4. See also *Svoronos*, Plate 79, nos. 1–7.
Pb content 5·2 per cent.

Pb-607 Coin of Athens, New Style. *c.* 88 B.C.
Obv. Head of Athena r., wearing crested Corinthian helmet.
Rev. A E / Θ Zeus, naked, hurling thunderbolt r., l. arm extended; in field r., symbol, star between crescents.
Wt. = 8·5 g. Size = 19×4·5 mm. Soft, brittle, weak metal with grey fracture. Slight internal corrosion.
Ref. Caley (1939), p. 41, no. 6. See also *Svoronos*, Plate 81, nos. 45–8.
Pb content 13·3 per cent.

Pb-608 Coin of Athens, New Style. Mid-second century B.C.
Obv. Head of Athena Parthenos r.
Rev. A ΘE Tripod; in field l., poppy head; in field r., thunderbolt.
Wt. = 9·1 g. Size = 20×4·7 mm. Rather soft, brittle, weak metal with grey fracture. Slight internal corrosion.
Ref. Caley (1939), p. 41, no. 5. See also *Svoronos*, Plate 80, nos. 1–7.
Pb content 9·9 per cent.

Pb-609 Coin of Athens, New Style. Early first century B.C.
Obv. Head of Athena Parthenos r.
Rev. A Θ E Sphinx seated r., wearing modius.
Wt. = 5·2 g. Size = 20×3 mm. Soft, brittle, weak metal with grey fracture. Considerable internal corrosion.
Ref. Caley (1939), p. 41, no. 7. See also *Svoronos*, Plate 80, nos. 18–21.
Pb content 20·4 per cent.

Pb-610 Coin of Athens, Early Series. 330–307 B.C.
Obv. Head of Athena r., wearing triple-crested Corinthian helmet.
Rev. A Θ H Owl l., in wreath.
Wt. = 3·7 g. Size = 15×3·3 mm. Hard, brittle generally sound metal with yellowish-brown fracture and local internal corrosion.
Ref. Caley (1939), p. 30, no. 1. See also *Svoronos*, Plate 22, nos. 85–8.
Pb content 4·2 per cent.

Pb-611 Coin of Athens, Early Series. 330–307 B.C.
Same type coin as Pb-610.
Wt. = 3·7 g. Size = 15×3·7 mm. Hard, brittle, sound metal with yellowish-grey fracture.
Ref. Caley (1939), p. 30, no. 2. See also *Svoronos*, Plate 22, nos. 85–8.
Pb content 5·4 per cent.

Pb-612 Coin, Laconia. 146–32 B.C.
Obv. Not given by Caley.
Rev. ΛA Eagle r., wings closed; in field ΦI
Wt. = 4·5 g. Size = 18×2 mm. Soft, tough, somewhat corroded metal.
Ref. Caley (1939), p. 72, no. 13. See also *B.M.C. Peloponnesus*, p. 124, no. 34; Plate XXIV, nos. 9 and 10 similar.
Pb content 10·7 per cent.

Pb-613 Coin, As of Licinius Murena, Rome. *c*. 159 B.C.
Wt. = 20·2 g.
Ref. Caley (1939), p. 104, no. 11.
Pb content 16·8 per cent.

Pb-614 Coin of Seleucus IV, Syria. 187–175 B.C.
Obv. Head of Apollo in archaistic style.
Rev. ΒΑΣΙΛΕΩΣ ΣΕLEYKOY Apollo standing l., naked; holds in r. arrow, . elbow rests on tripod: serrated edge.

Wt. = 8·9 g. Size = 21×3 mm. Moderately brittle, weak metal with local internal corrosion.
Ref. Caley (1939), p. 92, no. 3. See also *B.M.C. Seleucid Kings*, Plate X, no. 9.
Pb content 13·1 per cent.

Pb-615 Coin of Apameia. 133–48 B.C.
Obv. Head of Zeus r., wearing oak-wreath. ΑΠΑΜΕ
Rev. ΗΡΑΚΛΕΙ ΕΓΛΟ Cultus-statue of Artemis Anaïtis.
Wt. = 7·5 g. Size = 20×3 mm. Moderately hard, tough, sound metal.
Ref. Caley (1939), p. 88, no. 4. See also *B.M.C. Phrygia*, p. 81, nos. 67–70.
Pb content 5·1 per cent.

Pb-616 Coin of Apameia. 133–48 B.C.
Same type coin as Pb-615.
Wt. = 7·5 g. Size = 20×3·5 mm. Moderately hard, tough, sound metal.
Ref. Caley (1939), p. 87, no. 3. See also *B.M.C. Phrygia*, p. 81, nos. 67–70.
Pb content 6·4 per cent.

Pb-617 Coin struck in Sardis during the reign of Tiberius. A.D. 14–38.
Obv. {ΚΑΙΣΑΡ ΣΕΒΑΣ ΤΟΥΥΙΟΣ} Head of Tiberius r., bare.
Rev. {ΣΑΡ ΔΙΑΝΩΝ ΟΠΙΝΑΣ ΑΚΙΑΜΟΣ} In an oak-wreath.
Wt. = 5·6 g. Brittle metal with extensive surface corrosion.
Ref. Caley (1939), p. 88, no. 8. See also *B.M.C. Lydia*, p. 251, no. 102.
Pb content 16·6 per cent.

Pb-618 Autonomous coin of Antioch. First century B.C.
Obv. Head of Zeus r., laur.: border of dots. ΑΝΤΙΟΧΕΩΝ
Rev. ΤΗΣ ΜΗΤΡΟΠΟΛΕΩΣ Zeus wearing himation, seated l. on throne; in r., Nike; in l., sceptre.
Wt. = 8·2 g. Size = 19×3 mm. Moderately hard, tough, slightly corroded metal.
Ref. Caley (1939), p. 93, no. 7. See also *B.M.C. Galatia, Cappadocia, and Syria*, p. 156, nos. 41–2.
Pb content 9·6 per cent.

Pb-619 Imperial large bronze coin of Athens. 27 B.C.–A.D. 14.
Obv. Bust of Athena r., wearing Corinthian helmet with narrow horse-hair crest, high bowl; hair loose on neck; she wears aegis with serpents standing erect.
Rev. Θ A H Bucranion.
Wt. = 10·5 g. Size 24×3·9 mm. Moderately soft brittle, sound metal with grey fracture.
Ref. Caley (1939), p. 43, no. 1. See also *Svoronos*, Plate 99, no. 6.
Pb content 10·4 per cent.

Pb-620 Coin of Antiochus VIII, Syria. 121 B.C.
Obv. Head of Antiochus r., radiate. ΒΑΣΙΛΕΩΣ
Rev. ΑΝΤΙΟΧΟΥ ΕΠΙΦΑΝΟΥΣ Eagle with closed wings l.
Wt. = 5·8 g.
Ref. Caley (1939), p. 93, no. 5. See also *B.M.C. Seleucid Kings*, Plate XXIV, no. 4.
Pb content 31·7 per cent.

Pb-621 Coin of Septimius Severus possibly struck in Rome. A.D. 208.
Obv. Bust of Septimius Severus, laur. r. Legend mostly illegible.
Rev. Emperor riding on horseback to l. Legend mostly illegible.
Wt. = 21·4 g. Size = 32 mm.
Ref. Caley (1964), pp. 74–5, no. 4. See also *B.M.C.*, vol. V, p. 349.
Pb content 17 per cent.

Pb-622 Coin of Hadrian, Alexandria. A.D. 117–38.
Obv. Head of Hadrian r., laur.; wears aegis. Inscription illegible.
Rev. Tyche recumbent l. on couch, in r. holds rudder. Date illegible.
Wt. = 19·9 g. Size = 31×3 mm. Moderately hard, sound metal.
Ref. Caley (1939), p. 101, no. 2. See also *B.M.C. Alexandria*, p. 86, no. 727.
Pb content 30·0 per cent.

Pb-623 Coin of Antiochus VIII. 114 B.C.
Obv. Head of Antiochus r., radiate. ΒΑΣΙΛΕΩΣ
Rev. ΑΝΤΙΟΧΟΥ ΕΠΙΦΑΝΟΥΣ Eagle with closed wings l., over shoulder, sceptre.
Wt. = 5·9 g. Size = 20×2·5 mm. Soft, slightly brittle, corroded metal.
Ref. Caley (1939), p. 93, no. 6. See also *B.M.C. Seleucid Kings*, p. 90, no. 25 similar.
Pb content 24·9 per cent.

Pb-624 Coin of Demetrius II struck in or for Phoenicia. 146–138 B.C.
Obv. Head of Demetrius r., diad. ΒΑΣΙΛΕΩΣ
Rev. ΔΗΜΗΤΡΙΟΥ ΤΥΡΙΩΝ Hinder part of galley l.
Wt. = 5·7 g. Size = 18×2 mm. Hard, brittle, slightly corroded metal.
Ref. Caley (1939), pp. 92–3, no. 4. See also *B.M.C. Seleucid Kings*, p. 60, nos. 20–2; Plate XVIII, no. 4 similar.
Pb content 11·8 per cent.

Pb-625 Coin of Trajan struck at Antioch. A.D. 98–117.
Obv. Head of Trajan r., laur.; legend illegible.
Rev. SC within laurel-wreath.
Wt. = 13·5 g. Size = 25×3 mm. Moderately hard, sound metal.
Ref. Caley (1939), p. 93, no. 8. See also *B.M.C. Galatia, Cappadocia, and Syria*, pp. 183–5.
Pb content 9·2 per cent.

Pb-626 Coin of Philip II struck in Antioch. A.D. 244–9.
Obv. ΑVΤΟΚΚΜΙΟVΛΙΦΙΛΙΠΠΟCCΕΒ Bust of Philip jun. r., laur., wearing paludamentum and cuirass.
Rev. ΑΝΤΙΟΧΙΕΩΝ ΜΗΤΡΟΚΟΛΩΝ Female bust (the Tyche of Antioch) r.,

draped, veiled, and turreted; above, ram running r., looking back; in field, ΔE and SC; beneath bust, star.

Soft, weak metal.

Ref. Caley (1939), p. 93, no. 9. See also *B.M.C. Galatia, Cappadocia, and Syria*, p. 219.

Pb content 26·5 per cent.

Pb-627 Coin of Trajan, Alexandria. *c.* A.D. 111.

Obv. AVT TPAIANC ΕΒΓΕΡΜΔΑΚΙΚ Bust r., laur.; wears paludamentum and cuirass.

Rev. Emperor in quadriga r., horses walking; holds branch of laurel and standard; above.

Wt. = 21·3 g. Size = 35×3 mm. Hard, very brittle metal with grey fracture. Extensively corroded throughout.

Ref. Caley (1939), p. 101, no. 1. See also *B.M.C. Alexandria*, p. 62, no. 517.

Pb content 21·9 per cent.

Pb-628 Coin of Marcus Aurelius, probably struck in Rome. A.D. 171–2.

Obv. Head of Marcus Aurelius, laur., r. M ANTONINVS AVG TRP XXVI

Rev. Roma seated l., on cuirass, holding sceptre; her l. elbow resting on a round shield; behind her an oval shield. IMP VI COS III. In field, S C

Wt. = 23·6 g. Size = 27–30 mm. Fine externally, corroded to some extent internally.

Ref. Caley (1964), p. 74, no. 1. See also *B.M.C.*, vol. IV, p. 662, no. 1420, and *R.I.C.* III, no. 1037.

Pb content 9·6 per cent.

Pb-629 Coin of Commodus, probably struck in Rome. A.D. 189.

Obv. Head of Commodus, laureate, r.
M COMMOD ANT P FELIX AVG BRIT PP

Rev. Minerva standing l., holding Victory and spear; shield l., trophy r. MINER VICT PM TRP XIIII IMP VIII COS V DES VI. In field, S C

Wt. = 20·7 g. Size = 27–30 mm. Condition: fair.

Ref. Caley (1964), p. 74, no. 3. See also *B.M.C.*, vol. IV, p. 823, no. 637, and *R.I.C.* III, no. 546.

Pb content 13·4 per cent.

Pb-630 Coin of Maximian struck in London. *c.* A.D. 300 onward.

Obv. [IM]P MΛXIMIΛNVS PF ΛVG

Rev. GENIO POPV-LI ROMΛNI

Wt. = 9·53 g.

Ref. *R.I.C.* VI, London, 18; and Cope and Billingham (1968 b), p. 71, no. A. 1.

Source: Ashmolean Museum, Oxford, via Dr. C. H. V. Sutherland.

Pb content 6·43 per cent.

Pb-631 Coin of Severus struck in London. A.D. 306–7.

Obv. SEVERVS NOBILISSIMVS CΛES

Rev. GENIO POPV-LI ROMΛNI

Wt. = 10·57 g.

Ref. *R.I.C.* VI, *London* 59a; and Cope and Billingham (1968 b), p. 71, no. B.M. 51.

Source: British Museum, via Mr. R. A. G. Carson.

Pb content 3·50 per cent.

Pb-632 Coin of Maxentius struck in Rome. *c.* A.D. 307.
(A suspected contemporaneous forgery.)
Obv. MΛXENTIVS PF ΛVG
Rev. CONSERV-VRB SVAE (hexa-style temple).
Wt. = 6·37 g.
Ref. R.I.C. VI, *Rome*, 163, but shorter rev. legend; and Cope and Billingham (1968 a), p. 53, no. B.M. 52.
Source: British Museum.
Pb content 5·65 per cent.

Pb-633 Coin of Diocletian struck in Rome. *c.* A.D. 299.
Obv. IMP C DIOCLETIAN[VS] PF AVG
Rev. GENIO P[OP]-VLI ROMANI
Wt. = 7·26 g.
Ref. R.I.C. VI, *Rome*, 94a; and Cope and Billingham (1968 a), p. 53, no. N.M.W. 3.
Source: National Museum of Wales, via Mr. G. C. Boon.
Pb content 1·45 per cent.

Pb-634 Coin of Aurelian struck in Milan. *c.* A.D. 272–4.
Obv. IMP AURELIANVS AVG
Rev. FORTVNA REDVX
Wt. = 2·93 g.
Ref. R.I.C. V, 128; and Cope and Billingham (1968 a), p. 53, no. B.M. 68.
Source: British Museum.
Pb content 3·05 per cent.

Pb-635 Coin of Galerius struck in Siscia. *c.* A.D. 295.
Obv. GAL VAL MAXIMIANVS NOB C
Rev. GENIO POP-VLI ROMANI
Wt. = 9·28 g.
Ref. R.I.C. VI, *Siscia*, 90b; and Cope and Billingham (1967), p. 4, no. Br. 14.
Source: City of Bristol Museum, via Mr. L. V. Grinsell.
Pb content 2·80 per cent.

Pb-636 Coin of Constantius II struck in Heraclea. A.D. 351–4.
Obv. DN CONSTAN-TIVS PF AVG
Rev. FEL TEM[P RE]-PARATIO (falling horseman 3).
Wt. = 4·25 g.
Ref. L.R.B.C. II, 1893; and Cope and Billingham (1967), p. 5, no. B.M. 46.
Source: British Museum.
Pb content 6·89 per cent.

Pb-637 Coin of Diocletian struck in Antioch. A.D. 299–300.
Obv. IMP C DIOCLETIANVS PF AVG
Rev. GENIO POPV-LI ROMANI
Wt. = 9·54 g.
Ref. R.I.C. VI, *Antioch*, 52a; and Cope and Billingham (1968 b), p. 71, no. B.M. 48.
Source: British Museum.
Pb content 2·65 per cent.

Pb-638 Coin of Diocletian struck in Alexandria. *c.* A.D. 302–3.
Obv. IMP C DIOCLETIANVS PF AVG
Rev. GENIO POPV-LI ROMANI
Wt. = 10·98 g.
Ref. R.I.C. VI, *Alexandria*, 34a; and Cope and Billingham (1967), p. 4, no. M. 4.
Source: Manchester Museum, via Professor F. C. Thompson.
Pb content 3·14 per cent.

Pb-639 Coin of Maximinus Daza struck in Alexandria. Early A.D. 311.
Obv. IMP C GAL VAL MAXIMINVS PF AVG
Rev. GENIO IMP-ERATORIS
Wt. = 6·29 g.
Ref. R.I.C. VI, *Alexandria*, 124; and Cope and Billingham (1968 a), p. 53, no. B.M. 55.
Source: British Museum.
Pb content 3·94 per cent.

Pb-640 Coin of Constantius I struck in Lyons. *c.* A.D. 298.
Obv. CONSTVNTIVS NOB CAES
Rev. GENIO POPV-LI ROMANI
Wt. = 8·47 g.
Ref. R.I.C. VI, *Lyons*, 53a; and Cope and Billingham (1968 b), p. 71, no. N.M.W. 8.
Source: National Museum of Wales, via Mr. G. C. Boon.
Pb content 5·56 per cent.

Pb-641 Coin of Constantius I struck at Lyons. *c.* A.D. 295.
Obv. CONSTΛNTIVS NOB CAES
Rev. GENIO POPVLI ROMANI
Wt. = 9·51 g.
Ref. R.I.C. VI, *Lyons*, 6; and Cope and Billingham (1968 b), p. 71, no. B.M. 47.
Source: British Museum.
Pb content 1·81 per cent.

Pb-642 Coin of Diocletian struck at Trier. A.D. 300–1.
Obv. IMP DIOCLETIANVS [AV]G
Rev. M·SACRA AVGG ET CAESS N[N]
Wt. = 10·14 g.
Ref. R.I.C. VI, *Trier*, 474; and Cope and Billingham (1968 a), p. 53, no. B.M. 49.
Source: British Museum.
Pb content 3·01 per cent.

Pb-644 Coin of Maxentius struck in Rome. A.D. 309–10.
Obv. IMP C MAXENTIVS PF AVG
Rev. CONSERV-VRB SVAE
Wt. = 6·62 g.
Ref. R.I.C. VI, *Rome*, 210; and Cope and Billingham (1971), no. N.M.L. 6.
Source: Narodni Muzej, Ljubljana, via Dr. A. Jeločnik.
Pb content 12·31 per cent.

Pb-645 Coin of Maxentius struck in Ostia. A.D. 308.
Obv. IMP C MAXENTIVS PF AVG
Rev. AETE-RNITAS A-VG N
Wt. = 5·70 g.
Ref. R.I.C. VI, *Ostia*, 16; and Cope and Billingham (1971), no. N.M.L. 7.
Source: Narodni Muzej, Ljubljana, via Dr. A. Jeločnik.
Pb content 8·39 per cent.

Pb-646 Coin of Honorius struck in Constantinople. A.D. 393–5.
Obv. DN HONORIVS PF ΛVG
Rev. GLORIA-ROMANORVM
Wt. = 4·42 g.
Ref. L.R.B.C. II, 2188. Cope no. B.M 67.
Source: British Museum.
Pb content 5·00 per cent.

Pb-647 Coin of Allectus struck in London. A.D. 296. ('Quinarius'.)
Obv. IMP C ALLECTVS PF AVG
Rev. VIRTVS AVG, small galley.
Wt. = 2·33 g.
Ref. R.I.C. 55. Cope no. C.J.O. 25.
Source: Anonymous donor.
Pb content 2·93 per cent.

Pb-648 Coin of Septimius Severus struck in Rome. A.D. 195–6.
Obv. L SEPT SEV PERT ΛVG IMP VII
Rev. PM TRP III COS II PF, S-C
Wt. = 17·18 g.
Ref. R.I.C. IV, p. 188, no. 706; and Cope (1971), no. U. of S. 4.
Source: University of Surrey, via Professor M. B. Waldron.
Pb content 12·05 per cent.

Pb-657 Coin of unknown type. (Probably Roman Imperial.) Excavated by the author at Beth She'arim. From beneath the large slab of ancient glass, embedded in plastery conglomerate near floor of cistern.
Ref. R. H. Brill and J. F. Wosinski, 'A huge slab of glass in the ancient necropolis of Beth She'arim', *Proceedings of the VIIth International Congress on Glass*, Section B, Paper no. 223, 1965; and R. H. Brill, 'A great glass slab from ancient Galilee', *Archaeology*, XX, no. 2, April 1967, pp. 88–95.
Pb content *c.* 4 per cent. (Estimated by Martin Aitken.)

Pb-692 Coin of Gratian struck in Heraclea. A.D. 378–83.
Ref. L.R.B.C. II, 376 (Æ2, of 22·5 mm. die-module.) Cope no. B.M. 62.
Source: British Museum, via Mr. R. A. G. Carson.
Pb content 17·73 per cent.

Pb-693 Coin of Galerius struck in London. *c.* A.D. 300. (Large follis.)
Ref. R.I.C. VI, *London*, 15; and Cope (1968), pp. 124–5, no. A. 2.
Source: The Ashmolean Museum, via Dr. C. H. V. Sutherland.
Pb content 2·19 per cent.

Pb-694 Coin of Nero struck in Rome. A.D. 64–8. (Denarius.)
Ref. R.I.C. 58; and Cope (1971), no. A. 9.
Source: The Ashmolean Museum, via Dr. C. H. V. Sutherland.
Pb content 0·78 per cent.

Pb-695 British forgery of a first-century dupondius of Domitian.
Third-century A.D. fabrication.
Ref. R. A. G. Carson, 'The Leysdown (Kent) hoard of early Roman Imperial bronzes', *NC* 1971. Cope no. Ma. 1B.
Source: Maidstone Museum, via British Museum.
Pb content 13·86 per cent.

Pb-696 Coin of Gallienus struck in Rome. A.D. 266–8.
Ref. R.I.C. 178. (Antoninianus.) Cope no. W. 12.
Source: The Warrington Museum and Art Gallery, via Mr. J. R. Rimmer.
Pb content 6·51 per cent.

Pb-697 Coin of Hadrian struck in Rome. A.D. 118.
Ref. R.I.C. 546 (a). (Copper As.) Cope no. B. 17.
Source: The City of Birmingham Museum and Art Gallery, via Mr. A. J. H. Gunstone.
Pb content 2·10 per cent.

Pb-698 Coin of Commodus struck in Rome. A.D. 183–4.
Ref. R.I.C., Commodus 400 A (a). (Sestertius.) Cope no. B. 41.
Source: The City of Birmingham Museum and Art Gallery, via Mr. A. J. H. Gunstone.
Pb content 7·33 per cent.

Pb-699 Coin of Diva Mariniana struck in Rome. A.D. 253–9.
Ref. R.I.C. V, p. 65, no. 9. (Dupondius.) Cope no. B. 121.
Source: The City of Birmingham Museum and Art Gallery, via Mr. A. J. H. Gunstone.
Pb content 22·43 per cent. Full analysis to be published.

Silver coins and silver objects

The samples numbered in the Pb-700 series were provided by Dr. Adon A. Gordus. The descriptions, which were furnished by Dr. Gordus, also give his University of Michigan catalogue numbers. Analyses of some of these and of many related objects are discussed in references cited in this text, p. 282 n. 1.

Pb-750 Parthian coin; *c.* A.D. 100 (UM 4066).

Pb-751 Sasanian coin, Shapur I; *c.* A.D. 250 (UM 1780). Ag approx. 92 per cent.

Pb-752 Sasanian coin, Shapur II; *c.* A.D. 350 (UM 1815). Ag approx. 94 per cent.

Pb-753 Sasanian coin, Yezdigerd I; *c.* A.D. 410 (UM 1804). Ag approx. 95 per cent.

Pb-754 Sasanian coin, Khousrau I (Regnal year 45); *c.* A.D. 575. Minted at Zarang (?) (UM 3977). Ag approx. 95 per cent.

Pb-755 Sasanian coin, Khousrau II (Regnal year 8); *c.* A.D. 600. (UM 2180). Ag approx. 95 per cent.

Pb-756 Sasanian coin, Khousrau II (Regnal year 30); *c.* A.D. 625. (Mint ŠB or AB) (UM 2735). Ag approx. 95 per cent.

Pb-757 Umayyad coin; *c.* A.D. 720. Minted in Damascus (UM 4024). Ag approx. 98 per cent.

Pb-780 Metal from Achaemenid or Parthian vase, possibly authentic, in a private collection in Paris. (UM H-2002).

Pb-781 Small fragment of metallic silver, possibly scrap from a silversmithing shop. Nushijan, excavated fragment; Parthian or Achaemenid Period (UM H-2000). *Ref. Journal of the British Institute for Persian Studies*, vol. III, 1969. Courtesy of the British Institute of Persian Studies.

Pb-782 Metal from the foot of a purported Sasanian or Achaemenid bowl obtained in Iran (UM H-2006).

A gold coin

Pb-900 Coin of John II Comnenus (A.D. 1118–43), a gold nomisma. Struck in Constantinople. *Ref.* Similar to or possibly the same as no. 8, Plate LXVI, in *Imperial Byzantine Coins in the British Museum*, 1908; and no. 11, Plate LIII in J. Sabatier, *Monnaies Byzantines*, p. 196 and Plate LIII. This coin was sampled by a very light filing on its perimeter. (When received it had already been pierced.) The coin was provided by Mr. Timothy Boatswain. We thank Mr. Lawrence Majewski for helping with the identification of this coin.

An Indian coin and galena ore

Pb-248 Lead coin of the Kshatrapa Period (*c.* A.D. 100–*c.* 400).
Excavated at Nagara in Cambay Taluka, Kaira District, Gujarat State, India, by Professor R. N. Mehta. A sample of the coin was provided by Professor K. T. M. Hegde who has published a chemical analysis of the coin.
Obv. Kshatrapa motif of bull.
Rev. Mountain and moon symbols.
Square in shape, *c.* 15 mm. along edge, worn and thickly coated with corrosion products. (The laboratory sample consisted of uncorroded metal removed from the interior.)
Ref. See above, p. 281 n. 3.

Pb-249 A specimen of galena ore from Zawar, India. (Zawar is fifteen miles south of Udaipur, in the Aravalli region, and about 180 miles from Nagara.) This specimen was also provided by Professor Hegde.

TABLE I

Isotope ratios for lead extracted from ancient coins

Sample	Description	Pb^{208}/Pb^{206}	Pb^{207}/Pb^{206}	Pb^{204}/Pb^{206}
602	Egypt/Cyprus, 146–127 B.C.	2·0604	0·8317	0·05307
603	Egypt/Cyprus, 146–127 B.C.	2·0610	0·8318	0·05310
604	Egypt-Alexandria, 169–146 B.C.	2·0613	0·8321	0·05307
605	Athens, 307–283 B.C.	2·0608	0·8319	0·05304
606	Athens, second century B.C.	2·0617	0·8327	0·05304
607	Athens, *c.* 88 B.C.	2·0626	0·8325	0·05304
608	Athens, mid-second century B.C.	2·0628	0·8323	0·05308
609	Athens, early first century B.C.	2·0653	0·8330	0·05305
610	Athens, 330–307 B.C.	2·0630	0·8329	0·05314
611	Athens, 330–307 B.C.	2·0635	0·8329	0·05315
612	Laconia, 146–32 B.C.	2·0664	0·8326	0·05311
613	Rome, *c.* 159 B.C.	2·0646	0·8329	0·05313
614	Syria, 187–175 B.C.	2·0638	0·8326	0·05310
615	Apameia, 133–48 B.C.	2·0634	0·8329	0·05317
616	Apameia, 133–48 B.C.	2·0676	0·8339	0·05312
617	Sardis, A.D. 14–38	2·0687	0·8341	0·05318
618	Antioch, first century B.C.	2·0693	0·8341	0·05311
619	Athens, 27 B.C.–A.D. 14	2·0697	0·8343	0·05323
620	Syria, 121 B.C.	2·0818	0·8341	0·05318
621	Rome (?), A.D. 208	2·0778	0·8386	0·05347
622	Alexandria, A.D. 117–38	2·0784	0·8389	0·05350
623	Syria, 114 B.C.	2·0814	0·8370	0·05341
624	Phoenicia/Syria, 146–138 B.C.	2·0858	0·8439	0·05400
625	Antioch, A.D. 98–117	2·0864	0·8436	0·05384
626	Antioch, A.D. 244–9	2·0832	0·8432	0·05390
627	Alexandria, *c.* A.D. 111	2·0906	0·8474	0·05414
628	Rome, A.D. 171–2	2·0910	0·8477	0·05422
629	Rome, A.D. 189	2·0902	0·8462	0·05409
630	London, A.D. 300	2·0870	0·8482	0·05424
631	London, A.D. 306–7	2·0872	0·8475	0·05419
632	Rome, A.D. 307	2·0974	0·8517	0·05444
633	Rome, *c.* A.D. 299	2·0888	0·8466	0·05405
634	Milan, *c.* A.D. 272–4	2·0885	0·8459	0·05406
635	Siscia, A.D. 295	2·0882	0·8458	0·05396
636	Heraclea, A.D. 351–4	2·0809	0·8417	0·05374
637	Antioch, A.D. 299–300	2·0840	0·8435	0·05382
638	Alexandria, A.D. 302–3	2·0848	0·8445	0·05392
639	Alexandria, early A.D. 311	2·0862	0·8448	0·05397
640	Lyons, *c.* A.D. 298	2·0893	0·8461	0·05394
641	Lyons, A.D. 295	2·0877	0·8476	0·05411
642	Trier, A.D. 300–1	2·0865	0·8460	0·05409
644	Rome	2·0897	0·8480	0·05398
645	Ostia	2·0879	0·8454	0·05396
646	Constantinople, A.D. 393–5	2·0763	0·8390	0·05354
647	London, A.D. 296	2·0879	0·8481	0·05424
648	Rome, A.D. 195–6	2·0885	0·8461	0·05401

TABLE I (*cont.*)

Sample	Description	Pb^{208}/Pb^{206}	Pb^{207}/Pb^{206}	Pb^{204}/Pb^{206}
657	Beth She'arim (?)	2·0881	0·8433	0·05389
692	Heraclea, A.D. 378–83	2·0856	0·8442	0·05417
693	London, *c.* A.D. 300	2·0866	0·8474	0·05440
694	Rome, A.D. 64–8	2·0898	0·8498	0·05454
695	British, third century A.D.	2·0925	0·8480	0·05422
696	Rome, A.D. 266–8	2·0884	0·8457	0·05417
697	Rome, A.D. 118	2·0899	0·8472	0·05419
698	Rome, A.D. 183–4	2·0920	0·84745	0·05440
699	Rome, A.D. 253–9	2·0906	0·84700	0·05415
248	Lead coin, India	2·1318	0·8833	0·05632
249	Ore from Zawar, India	2·2040	0·9500	0·06070
750	Parthian, *c.* A.D. 100	2·0745	0·8360	0·05366
751	Sasanian, *c.* A.D. 250	2·0807	0·8414	0·05381
752	Sasanian, *c.* A.D. 350	2·0919	0·8450	0·05411
753	Sasanian, *c.* A.D. 410	2·0916	0·8477	0·05411
754	Sasanian, *c.* A.D. 575	2·0919	0·8453	0·05399
755	Sasanian, *c.* A.D. 600	2·0957	0·8497	0·05427
756	Sasanian, *c.* A.D. 625	2·0825	0·8411	0·05373
757	Umayyad, Damascus, *c.* A.D. 720	2·0850	0·8453	0·05402
780	Achaemenid or Parthian vase; possibly authentic	2·1093	0·8642	0·05542
781	Nushijan, (Excavated) Achaemenid or Parthian	2·0737	0·8304	0·05332
782	Achaemenid or Sasanian bowl; questionable authenticity	2·0893	0·8475	0·05419
900	Gold coin, Constantinople, A.D. 1118–43	2·0829	0·8479	0·05438