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THE EXPOSURE OF SOME ROMANO-BRITISH POPULATIONS TO LEAD

ABSTRACT — The author studied the lead concentration in prehistoric Roman skeletal remains found in England. He considers the intra vitam and post mortem uptake, the increase with the age of the individuals and the possible difference of the uptake due to the different sex of the studied skeletons. The anatomical site, from which the analyzed sample comes, is stressed.

KEY WORDS: Lead — Skeletal remains — Romano-British populations.

INTRODUCTION

Lead has several features which make it an attractive metal for cultures whose technology is relatively simple. It is easy to smelt from its chief ore, galena (lead sulphide) which is widely distributed and could have been picked up from the ground by early man. Gowland (1901) considered that galena was first smelted accidentally by being placed on a camp fire; the effect would have been startling for, as Percy (quoted by Gowland, p 361) noted, 'The hard brittle ore might in a greater or less degree be transformed, as though by magic, into soft malleable lead'. This soft malleable metal has a low melting point which makes it easy to cast or mould; it can be beaten out into thin sheets and easily formed into pipes; it can be joined together simply; it resists corrosion by water and is resistant to the elements and it can be easily reused and recycled. It also contains silver. Galena may contain up to 500 grams of silver per tonne. And it was this desirable property which was perhaps its main attraction for it was on the silver mines that the wealth of some of the most important of the ancient societies depended. Lead was also required for the recovery of silver from silver ores. This was achieved through the process of cupellation during which the silver was extracted from the ore in a furnace by the addition of lead; on further heating, lead oxide was formed which was either blown off the top of the vessel containing the molten mixture or, later, removed with twigs or other material leaving the silver behind. Cupellation was undoubtedly one of the most hazardous industrial processes ever invented and those who undertook this task would have almost certainly developed lead poisoning, and sooner rather than later. The dissemination of highly toxic lead oxide into the atmosphere would have rendered the immediate surroundings of the area highly dangerous to others.

The Romans, as is well known, used lead on a massive scale and on a *per capita* basis, probably used as much as modern Americans. They were greedy for almost all metals but expecially lead and tin and it was for its metallic wealth that they invaded Britain where lead was plentiful and easily obtained. Pliny (*Nat. Hist.* xxiv. 49) describes lead being found there "in the surface stratum of the earth in such abundance that there is a law prohibiting the production of more than a certain amount".

There can be little doubt that the Romans were heavily exposed to lead, principally from the adulteration of wine and from the use of lead in the preparation of some constituents of the diet. I have discussed this in more detail elsewhere (Waldron, 1973). What is equally certain is that they were well aware of the potentially harmful nature of their favourite metal. Vitruvius in *de Architectura* (VIII, 6) notes specifically that 'water is much more wholesome from earthenware than from lead pipes. For it seems to be made injurious by lead because cerusse is produced by it; and this is said to be harmful to the human body. He unequivocally recommended the use of earthenware pipes for conveying drinking water. Nevertheless, there must have been a good deal of lead poisoning in the Roman world although it is fanciful to ascribe the fall of the empire to this cause (see Sims, 1985) although, from time to time, the disease occurred on a grand scale. The first intimation we have of this is to be found in the writings of Paul of Aegena, who, in the seventh century, described an epidemic of colic ... having taken its rise in the country of Italy, but raging also in many other regions of the Roman empire, like a pestilential contagion, which in many cases terminates in epilepsy, but in others in paralysis of the extremities, and sometimes both these affections attacking together' (Adams, 1844). This combination of symptoms can only be attributed to lead poisoning.

This was true for Rome itself, but to what extent were the Roman colonists exposed to lead? Did Romanisation bring in its wake an increased risk of lead poisoning? To see how we might attempt to answer this question we need to turn for a moment to a consideration of the metabolism of lead.

Lead is absorbed through the lungs and from the gut but, except for those who work with lead, the major source of exposure is lead which is present in the diet, in food and drink. Lead which is absorbed is bound to the red blood cells and is distributed to the various organs and tissues of the body but principally to the skeleton. Lead is able to displace calcium from the bone crystal and over 90 % of the total amount of lead in the body is found within the skeletal tissues (including the teeth). Moreover, its residence time in the bones is measured in years and so it is found that bone lead concentrations rise with age until the sixth or seventh decades. Since the amount of lead in the skeleton is a function of lead absorption (and thus exposure) during life, it follows that it should be possible to predict the exposure of a given population from a consideration of their bone lead concentrations.

An important aspect of lead metabolism is that it is not laid down uniformly in the bone but tends to accumulate at the epiphysis, which is physiologically the most active part of the bone. Thus, the concentration in long bones is highest at the ends of the bone and lowest towards the middle (Brätter et al., 1977). There is also a difference in concentration between bones which may vary by a factor of two or more (Barry & Mossman, 1970). These are important points to bear in mind when studying lead exposure in the past by means of bone lead analyses since the samples must all be taken from the same bone in order to achieve uniformity in the results.

Lead concentrations in some Romano-British skeletons

I have been examining the lead content of bones from seven Romano-British sites, Bath, Cirencester, Henley Wood, Poundbury, West Tenter Street in London, Verulamium (modern St Albans) and York (see *Figure 1*). In all cases samples of rib were taken for analysis since the ribs almost always seem to survive well and can be used for destructive chemical analysis without sacrificing much anthropological or pathological information.

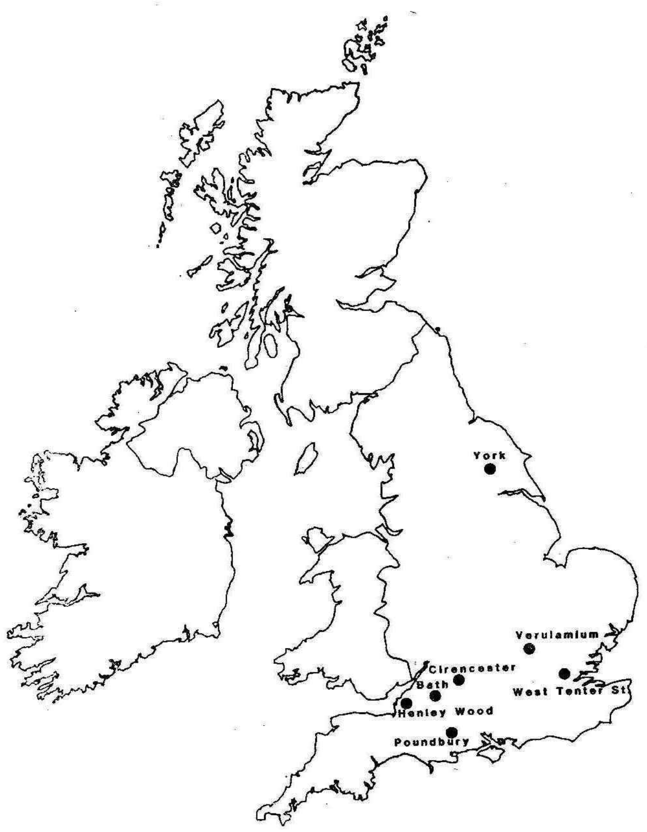

FIGURE 1. *Map to show position of Romano-British sites from which bones have been analysed for lead content.*

The analytical procedure has been described in detail elsewhere (Mackie et al., 1975) but in essence it consists of dissolving the bone in a mixture of nitric and perchloric acids prior to analysis by atomic absorption spectrophotometry. The results from the various sites are shown in *Table 1;* those from Poundbury have not been completely analysed yet and the results from this site should be regarded as preliminary. There is a more than eightfold difference in the means shown in the table from which one might be led to suppose that the populations represented at these sites experienced a very wide range of exposures. Reference to *Figure 2*, however, will show that this view needs some modification.

Figure 2 shows the percentage distribution of the bone lead concentrations for each of the sites where the numbers are sufficiently large; Cirencester, Henley

TABLE 1. *Lead concentrations (μg/g dry weight) in bones from some Romano-British sites in England*

	Mean	SD	*n*
Verulamium	30.6	4.7	5
Bath	55.6	27.7	10
York	63.5	31.6	77
Henley Wood	65.7	16.4	41
Poundbury	105.0	55.4	323
West Tenter Street	116.6	54.3	51
Cirencester	255.5	133.7	316

SD = standard deviation
n = number in sample

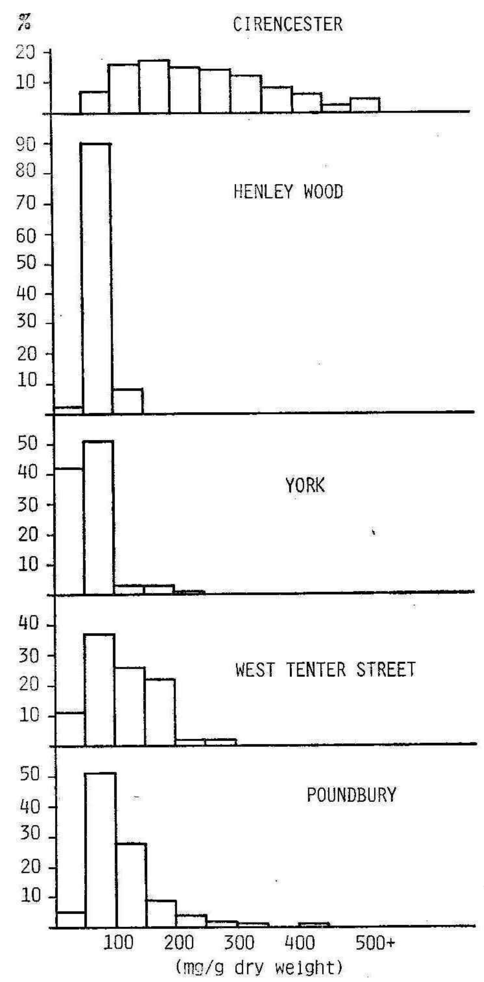

FIGURE 2. *Percentage distribution of bone lead concentrations (μg/g dry weight) from some Romano-British sites.*

Wood, Poundbury, West Tenter Street and York. The distribution of the concentrations from some of the sites is so unusual that it is improbable that they truly reflect the exposure of the original population. The most extreme case is that of Cirencester where not only is the mean concentration more than twice as great as the next highest (Poundbury with 105 μg/g) but the distribution curve is almost flat over its middle range, has no value less than 50 μg/g and has a considerable tail to the right. These considerations make it extremely likely that the results obtained at this site are anomalous. Henley Wood is also curious in that 90 % of the values fall in the range 50—100 μg/g whilst at York the distribution is markedly skewed to the left. At West Tenter Street the distribution is less unusual although somewhat skewed to the right; when the class intervals are reduced there is some indication that the distribution is bimodal (Waldron, forthcoming). Only at Poundbury is there anything which approximates to a normal distribution and even here, there is a considerable tail to the right.

The fact that the lead concentrations are not all (even approximately) normally distributed may have several explanations. The most obvious is that we are dealing with a non-random sample and this is certainly one of the most important factors which has to be taken into account when dealing with the interpretation of any data relating to populations of skeletons. Almost the entire process from burial to recovery is determined by non-random events; people are buried in particular cemeteries as the result of deliberate choices (either theirs or their relatives), the survival of the buried bones is largely dependent upon non-random events and the factors which determine which skeletons are recovered after burial are also not subject to procedures which would satisfy a statistician. It is perhaps no surprise, then, that data relating to skeletal remains (such as height, weight, age, bone lead concentrations) fail to follow the distribution which one expects from a random sample. The surprise is, that they should do so at all.

Thus we may be able to discount some of the anomalies seen in the bone lead concentrations on these grounds but another extremely important factor is the post-mortem absorption of lead from the soil. This is a matter which I have studied in some detail (Waldron, 1981, 1982, 1983) particularly when it became clear that some of the results which I was obtaining from bone lead analyses were biologically highly improbable. The bone mineral does not become chemically inert when it is buried, and the accumulation of some elements has been used for many years as a means of comparative dating. However, the geological evidence had suggested that lead in the soil was mobile only when the pH was low, that is, under conditions in which bone would not be well preserved. However, it was clear early on in our studies that bones in lead coffins could absorb lead in sufficiently large amounts to give concentrations which could not possibly have been present during life as is well demonstrated by the results obtained from bones found in lead coffins at Poundbury and West Tenter Street (*Table 2*). At West Tenter Street only two skeletons from lead coffins were analysed and in both the bone lead concentration was in excess of 11,000 μg/g; at Poundbury 16 skeletons from lead coffins were examined and in these the lead concentrations ranged from 341 to 14,362 μg/g. In almost none of these cases could such extremely high lead concentrations have accrued during life and bones from lead coffins must not be used in the estimation of lead exposure.

TABLE 2. *Lead concentrations (μg/g dry weight) in bones from lead coffins at two Romano-British sites*

Lead concentration	Sex	Age
West Tenter Street		
11,752	male	25
11,848	male	25
Poundbury		
341	juvenile	6
407	juvenile	5
525	female	adult
621	female	45
1,292	juvenile	8
1,965	male	40
3,241	male	40
4,387	male	30
5,467	male	30
5,649	male	30
8,649	juvenile	15
10,052	female	35
13,234	female	40
13,287	female	30
14,210	male	20
14,362	female	60

The concentrations in skeletons recovered adjacent to lead coffins should also be carefully scrutinied to ensure that they have not been unduly elevated by lead which has leached out from the lead coffin into the surrounding soil. If there is any doubt about the matter, then the safest course of action is to reject them from statistical analysis. At the West Tenter Street site this point was carefully examined but there was little evidence to suggest that the lead coffins had contaminated the soil beyond the immediate confines of the graves which had contained them.

It is evident, then, that bones in lead coffins may absorb lead to a considerable degree, but to what extent may lead be taken up from the soil? The answer is that it may be done to such a degree as to overwhelm the influence of any ante-mortem exposure. I can illustrate this by reference to data obtained from the site of Bordesley Abbey in Worcestershire. The Abbey was a Cistercian foundation which flourished during the 12th to the 16th centuries and was dissolved by Henry VIII in 1538. There were several burials at the site and from 23 of these we obtained samples of ribs and soil from the grave. The soil lead concentrations were somewhat unexpectedly found to have an extremely wide range (from 11—912 parts per million) and the bone lead concentrations were also distributed over a wide range (from 62—6,059 ug/g). There was a highly significant positive correlation between the lead concentrations in the bones and the soil ($r = 0.77$, $P < 0.001$) and about 59 % of the variance in the bone lead concentrations was due to lead in the soil. The intercept on the ordinate of the regression equation was *ca* 40 μg/g which may be taken as the mean bone lead concentration in the sample which was not due to lead in the soil; this is about the same as in a contemporary British population with no occupational exposure and may be compared with the mean of 682 μg/g calculated from the raw data.

Unusually high bone lead concentrations, therefore, should always raise the possibility of soil contamination. This seems to be the most plausible explanation for the Cirencester results particularly as we were able to demonstrate with the use of physical methods that virtually all the lead in a premolar from the site had been absorbed postmortem.

At Poundbury we had soil samples from only 46 graves and were able to show that in the skeletons contained in them, the contribution of lead from the soil was very much less than at Bordesley Abbey. At Poundbury only about 9 % of the variance in the bone lead concentrations could be explained by lead in the soil and the regression equation showed that the mean calculated from the raw data over-estimated the 'uncontaminated' mean by only about 26 %. Assuming that these 46 graves reflect the pattern throughout the cemetery as a whole, it can be seen that the Poundbury data probably do give a reasonable, if somewhat overestimated, view of lead exposure in Romano-British times.

There is another feature of lead metabolism which can be used to validate data relating to early populations. In modern populations it is found that the blood lead concentrations in adult females are always slightly lower than in adult males for reasons which are not entirely clear but probably reflect a lower uptake from the gut. The result of this is that females have a lower total body burden of lead than males of the same age and this reflects itself in lower bone lead concentrations. Assuming that the metabolism of lead is the same in modern and ancient populations, bones from archaeological sites should also show this sex difference and the increase in lead concentrations with increasing age to which I referred earlier.

At Poundbury the male skeletons do indeed have a higher lead concentration than the females (*Table 3*) and although small, the difference is significant ($P < 0.001$). The male skeletons at Henley Wood also have a higher lead concentration than the females but here the difference is not statistically significant.

TABLE 3. *Lead concentrations (μg/g dry weight) in bones from some Romano-British sites by sex*

	Males	Females
York		
Mean	60.2	85.5
SD	25.7	60.8
n	55	9
Henley Wood		
Mean	68.0	61.8
SD	20.4	7.1
n	16	11
West Tenter Street		
Mean	107.8	124.1
SD	54.7	53.0
n	39	12
Poundbury		
Mean	120.0	105.2
SD	57.0	60.1
n	125	135

At West Tenter Street and York, by contrast, the concentration in the females is higher than in the males but in neither case is the difference statistically significant and may be due in part to the relatively small numbers of female skeletons in the sample.

An increase in lead concentration with age (for both sexes combined) is found at Poundbury and

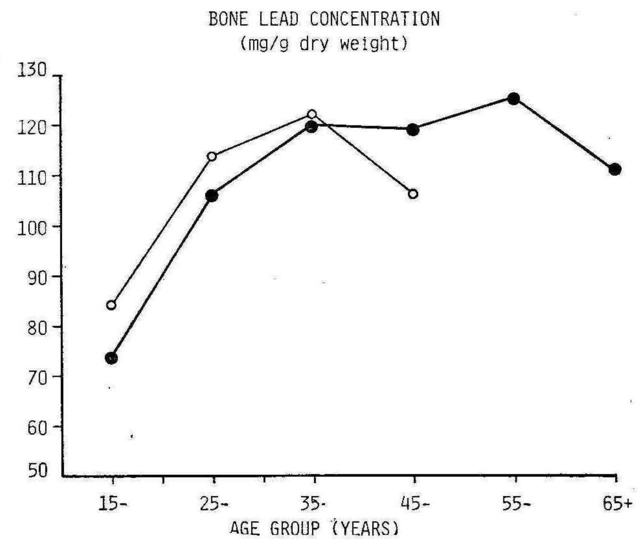

FIGURE 3. *Mean lead concentrations (μg/g dry weight) by age in bones from Poundbury (closed circles) and West Tenter Street (open circles).*

the life of these adults and not post-mortem absorption from the soil.

Lead concentrations in infants and juveniles

So far I have considered only lead concentrations in bones from adults. In the course of our investigations, however, we have analysed bones from infants and juveniles at Henley Wood, York and Poundbury. In each case the mean concentrations (*Table 5*) are much greater than would have been expected by comparison with present day levels. Two explanations for this offer themselves: either there was an extremely high prevalence of lead poisoning in the young, or juvenile bones absorb lead from the soil to a much greater degree than adult bones. The former explanation seems highly implausible for it would indicate that almost *all* the young children buried at these sites had died from lead poisoning and this is unlikely in the extreme. It is possible that *some* of the children were unusually heavily exposed and in this case, it should be possible to detect lead lines in the growing ends of the long bones. In some preliminary studies at Poundbury we have found diffuse areas of increased density in the limb bones of many juveniles (T. Molleson and T. Waldron, unpublished) but they are not typical of the classic lead line and further work is in hand to determine whether there is a relationship between their presence and the bone lead concentration.

TABLE 4. *Lead concentrations (μg/g dry weight) in bones from two Romano-British sites by age (both sexes combined)*

	Age range					
	15—	25—	35—	45—	55—	65+
West Tenter Street						
Mean	82.1	114.3	122.6	105.7*		
SD	29.5	59.5	58.9	44.9		
n	7	20	16	6		
Poundbury						
Mean	71.7	107.4	120.0	119.0	126.9	109.8
SD	39.5	46.0	51.7	53.4	100.6	44.6
n	21	63	61	59	31	18

* Includes all ages greater than 45.

at West Tenter Street (see *Figure 3* and *Table 4*). Both the rate of increase and the mean concentrations for each age range are similar at the two sites which strengthens the conclusion that the bone lead concentrations truly reflect exposure. At Poundbury there is a fall in lead concentration in the most extreme age group which is again in line with prediction since lead levels are known to fall in old age as the bones loose calcium and become porotic. (In this respect, as in many others, the metabolism of lead closely follows that of calcium.) The fact that sex and age differences can both be shown in the Poundbury data strengthens the conclusion that the main determinant of the bone lead concentrations is exposure experienced during

TABLE 5. *Lead concentrations (μg/g dry weight) in juvenile bones from some Romano-British sites*

	Mean	SD	*n*
York			
0— 5	59.2		2
6—15	58.2	22.8	6
Henley Wood			
5—15	69.3	18.2	6
Poundbury			
0— 5	73.9	26.6	25
5—15	69.7	18.7	23

At present, I am inclined to believe that the levels found in the very young are not a true reflection of their lead exposure in which case, the bones must be absorbing more lead post-mortem than those of the adults. I know of no evidence which would support this view, however, but it should be capable of experimental verification. Until we have more information, however, great care must be taken in the interpretation of these data.

Relative exposure of Romano-British populations

Perhaps the most interesting question is whether these bone lead concentrations allow us to say if the Romano-British populations to which they refer had a greater exposure to lead than their predecessors. We have been table to analyse a rather small number of bones from pre Romano-British sites and the results are lower than all those from the Romano-British sites except Verulamium (where the sample size is small). At Poundbury the mean concentration in the small number of early graves is less than half the Romano-British mean. The bones from the pre-metal working site at Hazelton contain substantially less than any of the Romano-British bones (*Table 6*).

TABLE 6. *Lead concentrations (μg/g dry weight) in bones from some pre Romano-British sites*

	Mean	SD	*n*
Hazelton (neolithic)	14.3	4.7	11
Bath (1600 B.C.)	33.3	8.3	6
Danbury (iron age)	34.9	4.5	35
Poundbury (iron age)	45.0	9.4	10

The two most reliable sets of data from the Romano-British sites are those from Poundbury and West Tenter Street and their mean concentrations indicate that these populations experienced an exposure to lead which was at least twice as great as earlier populations at Poundbury and an exposure seven or eight times as great as the neolithic farmers at Hazelton.

It is important to keep in mind that these are *relative* differences and the reported lead concentrations indicate trends rather than the exact concentrations during life. For example, we know that the Poundbury mean is likely to over-estimate the 'uncontaminated' mean by about a quarter; the lead concentrations in the crouched burials from the same site are likely to be similarly over-estimated but despite this, the difference between the two is real and shows which of the two populations had the greater lead exposure.

To what extent we can compare the concentrations from archaeological sites with modern population is somewhat more difficult since in the analysis of modern bone we are dealing with a different matrix and the problem of exchange with the soil does not, of course, arise. In modern bones the collagen/mineral ratio is much higher than in bones which have been buried for many centuries. The collagen in modern bones will add to the dry weight and tend to lower the bone lead concentration with respect to ancient bone since almost all the lead in bone is contained in the inorganic phase. With hind-sight we can say that it would have been more informative to have expressed the lead concentrations as a lead/calcium ratio and perhaps this should be recommended for future research although it will increase the cost of the investigations. Alternatively, it should be possible to derive a correction factor which could be used to compare lead concentrations in the dried inorganic phase with those the dried inorganic and organic phases; this is an area in which some further work would be very useful.

The source of the lead

The results of the bone lead concentrations reported here indicate that at least some Romano-British populations were exposed to lead to a much greater degree than earlier populations. We can say with certainty that, except for those employed in lead mining, smelting and fabrication, the lead must have come from the diet since airborne lead concentrations would have been so low as to be an insignificant source. It is by no means certain, however, which constituents of the diet were especially rich in lead. In southern England the use of lead water pipes would not have been a hazard because the water is hard and not plumbosolvent; water pipes from Bath, for example, are perfectly smooth and show no trace of corrosion. The water in the north, however, may be highly plumbosolvent and the use of lead water pipes or storage tanks can be extremely dangerous. (The ill effects of drinking water from lead pipes was 'rediscovered' in the 19th century and many cases of lead poisoning were attributed to contaminated water and the 'pale faces of the north' were considered to be the result of the disease on an endemic scale.)

In Rome itself, exposure is usually said to have resulted from the adulteration of wine, the preparation of sapa in lead-lined pots and the lining of bronze cooking pots with lead to prevent copper from the bronze from imparting a bitter taste to food prepared in them. (Further details may be found in Nriagu, 1983.) It would be unwise to assume, however, that the Roman colonists were exposed in a similar manner without much more evidence than is presently available. There was an extensive wine trade between Britain and the continent and presumably adulterated wines would have taken their place beside the pure vintages, but we are in no position to be able to say how much lead these imported wines contained.

Another important source of lead in the diet may have come from the use of lead glazed pottery. This was used extensively by the Romans even for mortaria which were used for grinding foodstuffs (see Arthur, 1978). Some preliminary work which we have undertaken has shown that in many cases the glaze was underfired and considerable amounts of lead can be extracted from it (Waldron, unpublished). There is little doubt that it would have been an important source of lead; indeed the Romano-British housewives may have actively contributed to the hazard since, if lead leaches into food from the glaze, it imparts a sweet taste to it, and, given the relative dearth of sweeteners, this might have been considered a positive attribute. Certainly this was the case in the eighteenth and nineteenth centuries.

Wine and pottery are, therefore, likely to have been amongst the most important of the sources of lead to which the Romano-British populations were exposed. Other archaeological clues to sources of exposure are meagre in the extreme and much more work is needed before they can be established with any certainty.

CONCLUSIONS

The results which have been summarised here show that bone lead concentrations may provide evidence which can be used to estimate relative levels of exposure in the past provided that certain conditions are observed:

1. Wherever possible, some estimate must be made of the contribution of post-mortem uptake from the soil to the bone lead concentration and due allowance made for it.

2. The bone lead concentrations should follow expected trends; the results should be higher in males than in females and there should be an increase in the concentration with age.

3. The samples taken for analysis must come from the same bone and the same part of the bone and comparisons should only be made with the results from other series if they refer to the same anatomical site. Comparisons can only be validly made if the concentrations are expressed in the same terms.

If, in any set of bone lead measurements, these conditions cannot be met then the results must be treated with great caution and so must any conclusions based on them.

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