LEAD EXPOSURE IN A MIDDLE CLASS POPULATION OF ANCIENT ROME (UNPUBLISHED REPORT)

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ABSTRACT

The cemetery population of Isola Sacra dates to the 2nd and 3rd centuries AD and consisted of middle class traders and craftsmen as suggested by tomb inscriptions. We present data to show that most of the skeletal remains (humans as well as domestic animals) at the site have become diagenetically contaminated with lead. Analysis of 22 bones from protected monumental tombs, believed to be free of post-mortem changes, shows average lead concentration of 10 µg/g, with the range being 0.87-36 µg/g. The observed bone lead levels are comparable to values that have been reported for many modern urban populations. Calculated average blood lead level was 10 µg/dL (range, 0.89-36 µg/dL) and suggest that exposure to lead was not just restricted to the aristocracy but was pervasive among all social classes of the Roman population. The health risk of the suspected lead exposure dose would have been marginal for the adult population but likely inimical to children. The isotopic composition of the bone lead suggests that the cemetery population obtained their lead from multiple ancient sources.

The aim of releasing this report is to encourage further debate and research on the role of lead poisoning in the decline of the ancient Roman Empire

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INTRODUCTION

Exposure of Roman populations to lead has fascinated scientists because of the claim that lead poisoning was a contributing factor to the decline of the Roman empire (Gilfillan, 1965; 1991; Nriagu, 1983). Since the skeleton is the primary long term storage compartment for lead in human body, bones can be used as a silent witness of Roman lead exposure at various times in their history and can provide a pragmatic estimate of lifetime exposure history for an individual. Attempts to use bone lead for estimating lifetime exposure in Roman times has remained problematic for several reasons. The common Roman practice of cremation has left us with relatively few samples (Aufderheide et al., 1992). Considerable complications are often introduced by post-mortem diagenesis and contamination of the bones in the burial environment (Waldron, 1981; Patterson et al., 1987). The bone samples may further be contaminated during collection and analysis (Hisanaga et al., 1988).

This report presents the concentrations and isotopic compositions ($^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$) of lead in bones of 98 individuals from the necropolis of Isola Sacra (located about 23 km west of Rome) who were interred between the 2nd and 3rd centuries AD (Testaguzza, 1964; Baldassarre, 1980). With about 2000 excavated individuals of both sexes and of all ages, this burial site represents one of the most significant skeletal collections of ancient Rome (Sperduti et al., 1999). An objective of this study is to investigate the effects of the different burial types and degree of bone preservation on diagenetic changes of bone lead levels at this necropolis. Inscriptions on tombstones show that the people who were buried at Isola Sacra were primarily men and women of business and commerce, frequently descended from slaves and showed no "tranche" in the social hierarchy at the top which one would associate with aristocracy of office or conventional elite status (Garnsey, 1999). The cemetery population came from a relatively egalitarian community of traders and craftsmen and their skeletal remains provides us with a unique opportunity for studying the exposure of a "middle class" Roman population to lead.

MATERIALS AND METHOD

Samples

A subset of 98 femoral midshaft bones were selected from the Isola Sacra skeletal samples being investigated at McMaster University. They had all previously been manually cleaned and rinsed in distilled water.

The preservation of bones at Isola Sacra has been categorized by Savore (1996) into "normal" (similar to fresh bone), "focalized" (with focal tunnels), "amorphous" (advanced stage of focalized category with less dense tunnels and lacking microstructures), and "mineralized" (organic material completely removed but still possible to recognize tissue morphology). Previous studies have generally found no relationships between the burial conditions and histological appearance (Grupe, 1999). It is generally believed that "normal" bones are less likely to have experienced diagenetic changes than decomposed samples, and several studies claim that "normal" samples were used to minimize any effects of post-mortem changes (Mackie et al., 1975; Jaworowski et al., 1985).

Bone samples from 11 different animals collected from the burial grounds of Isora Sacra were also digested and analyzed using the same procedure as the human bones. Lead contents of bones of domestic and farm animals provide a reference level against which human data may be compared in assessing the exposure to lead especially in ancient times.

Sample Digestion

The bone samples were subsequently washed twice in acetone in order to remove any acetone-soluble preservatives. They were then rinsed with 10 ml 0.1M (0.5%) HNO_3 for several minutes. The HNO_3 rinse solution was kept for graphite furnace atomic absorption spectrometry (GFAAS) and ICP-MS analysis. After rinsing with acid, each sample was heated in a muffle furnace at 250 ˚C for two hours, and then was weighed. A known weight (typically 0.2-0.5 g) of the sample was added to 5 ml concentrated, trace metal-grade HNO_3, and dissolved by heating in a decontaminated Pyrex beaker on a hot plate at 150 ˚C for 5-15 minutes. Each sample was diluted to standard volume with deionized water, typically 250 ml, before instrumental analysis.

Instrumentation

Lead content of the sample was determined on a graphite furnace atomic absorption spectrometer (GFAAS) equipped with a background corrector. Manufacturer recommended operating procedure was used in the GFAAS measurements. The isotopic composition of the lead was determined using an inductively coupled plasma-mass spectrometer (ICP-MS). Blanks were analyzed to track contamination from the reagents and during the processing and analysis of samples and values obtained were <1.0 μg/L for all reagents. A Standard Reference material (NIST Bovine Liver 1577b) was analyzed with each batch of samples.

Instrumental Analysis

A Finnigan MAT "ELEMENT" single-collector magnetic-sector ICP-MS was used in the study. Lead isotopic ratio measurements were performed in the "low-resolution" mode ($M/\Delta M= 400$), which provides flat top peaks. Great care was taken in tuning the instrument for optimal peak shape and minimal mass bias (smaller than 0.1% per atomic mass unit). The most sensitive parameters for the tuning affect the interface region of the ICP-MS and control the focus, shape, and extraction of the ion beam. The peak shape was tuned for a wide and flat plateau with zero slope. This allows for unbiased fast peak hopping, which is essential for a single-collector ICP-MS. The mass bias of the instrument can be influenced by tuning the Y-deflection parameter and by setting the magnetic mass for the fast electrical scanning mode. Sample introduction was performed with a double-spray chamber setup to achieve better short-term precision. The use of two spray chambers provides better mixing of the sample aerosol mostly due to the reduced dead volume. Two regular Scott-type spray chambers were connected at a right angle with a simple glass ground joint adapter, which was build to fit into a regular Teflon spray chamber endcap on the second chamber and the outlet of the first spray chamber. The first spray chamber was equipped with a micro concentric nebulizer (MCN-T1, CETAC, Omaha, NE) and cooled to ca 2°C. The second spray chamber was left at room temperature. The samples were pumped by a low-pulse, planetary gear head ISAMATEC (Switzerland) peristaltic pump at a flow rate of ca. 0.2 ml/min through the two spray chambers.

For isotope ratio measurements, the magnetic-sector ICP-MS was used in the electrical scan mode. This allows fast peak hopping scan routines. The magnet is set to a constant mass of up to 15% below the highest scanned mass. Electrical scanning is performed by altering the acceleration voltage. Fast peak hopping is a means to reduce the short-term noise of the ion beam by sequentially collecting all analyte masses in a small time window. Nevertheless, there are certain physical limits for reasonable scan regimes. Typically, scan times of 10-100 ms per isotope yield the best results. The selected scan times are a function of the number and intensity of the isotopes that need to be covered. Very short sampling times of less than 10 ms significantly reduce the effective duty cycle but are still not capable of filtering the higher frequency white noise of the ion source. The precision of the ion counting can only be as good as determined by the Poisson counting statistics. To ensure that counting statistics are not limiting the precision of the isotopic analyses at the desired level of maximal 0.1%, total scan times that provide a total number of counts 10 to 100 times above the minimum required by the Poisson statistics are employed. The external mass bias correction of the data is performed with the NIST 981 common lead isotopic reference material. The samples are run in a standard-sample-standard bracketing routine. The detector deadtime is carefully determined using the $^{175}Lu/^{176}Lu$ isotope system. Additionally, the samples and the 981 standard are run at closely matched concentration levels (1 ng/g ± 10-20%) so that the remaining deadtime error of ca ±1 ns becomes insignificant at the desired 0.1% precision level. The data evaluation and error reporting are performed in a most conservative way, and is based on the average value and the external precision of the bracketing reference material runs. The simple linear mass bias correction for a given sample is calculated with the average of the results for the two standards analyzed before and after a sample. Sample data are rejected and reanalyzed if the error (2 RSE - relative standard error) of the four bracketing standards exceeds the 0.1% precision level. Since most samples are analyzed only once, the internal precision of the sample runs is used as additional quality control. For the calculation of the internal RSE (see also table 1) the intensity values for each isotope of the 2000 scans are averaged to 20 blocks of 100 scans. Then the isotope ratios and standard error of the 20 blocks of averaged intensities are calculated. A sample run is rejected when the internal error of 2 RSE exceeds the 0.1% precision level. Based on the external precision of the standard runs and the internal precision for each sample about 10% of the results were rejected and the samples reanalyzed. Nevertheless, for almost all of the reanalyzed samples the new result differed by less than 0.1% from the previous result. This confirmed our very conservative approach for the error estimate and ensures the accuracy of the sample results to be within 0.1% (2 RSE).

Matrix Effects: The digests and leachates of the bone samples were analyzed without matrix separation. Hence, we had to ensure that the matrix of up to 0.1% total solids in solution had no significant impact on the isotope ratio data. The matrix consisting mostly of calcium the most abundant isotope of which has the same mass as ^{40}Ar, which forms by far most abundant ion in the argon plasma source of the ICP. Thus, matrix effects from ion or space charge interferences were unlikely. Nevertheless, the biggest challenge to investigating the matrix effect of calcium was to find suitable calcium standards with low and isotopically normal lead blanks. The cleanest solution was provided by High Purity Standards (Charleston, Virginia) in the form of their 10000 mg/L Ca ICP-MS standard. For levels of up to 1000 mg/L Ca we found no significant impact of the matrix on the isotope ratio of Pb. This level exceeds the highest possible level in the bone samples by at least a factor of two. For the isotope analyses all samples were at least diluted to the equivalent of 1g of bone sample dissolved in 1 L of total solution. Most samples were diluted to even lower levels based on their Pb concentration and the goal of 1 ng/g Pb in solution for the isotopic analyses.

RESULTS

Average concentration of lead in rinse acid solution was 0.2 ± 0.13 μg/L for human bones and 0.19 ± 0.16 μg/L for animal bones (Table 1). Rinsing the bones with dilute nitric acid resulted in minimal loss of lead from the samples irrespective of their state of preservation. A number of previous workers have interpreted the low acid leaching rate as evidence that diagenetic changes in the lead content was insignificant (Refs). As will be discussed below, diagenetic alteration was pervasive in the samples, and our data for the rinse solutions suggest only that any extraneous addition of lead to the bones was not by surface adsorption phenomenon. The mean $^{207}Pb/^{206}Pb$ (0.8434 ± 0.0025) and $^{208}Pb/^{206}Pb$ (2.0750 ± 0.0067) ratios in the rinse solutions were very similar to those of the bone samples (see below), implying little or no difference in the pool of lead in the bone that was removable with nitric acid.

In a number of previous studies bone samples were ashed at temperatures as high as 700^{o}C (see Grupe, 1999). For this study, samples were heated to 250^{o}C so as to minimize loss of lead by volatilization. At this temperature the organic component of the bone (mainly collagen) would only have been charred and the observed "loss on ignition" (LOI) would not reflect the total organic content of the samples. Our mean LOI was 9.8 ± 4.2% for human samples and 6.8 ± 1.1% for animal samples, and are lower than the mean LOI of approximately 20% reported by Grupe (1999). A more detailed analysis of organic residues in Isola Sacra bones (see Grupe, 1999) found that although burial type played a considerable role in the diagenetic history of the bones, there was no significant correlation between the trace element contents and percentage nitrogen or carbon in the samples. Our data are thus consistent with the previous study (Grupe, 1999) in that we do not find a significant correlation between the lead content and the LOI values.

The concentrations of lead in human bones analyzed varied widely, from 0.87 to 86 µg/g (Figure 1) with the average being 21 µg/g. About one third of the samples contained <10 µg/g Pb and the lead content of 57% of the samples was below 20 µg/g (Figure 2). The average concentration of lead in animal bones from Isola Sacra (21±14 µg/g; see Table 2) is identical to that for human beings.

The isotopic composition of lead in the samples is depicted in Figure 2. The average ratio for $^{207}Pb/^{206}Pb$ is 0.8468 (range, 0.8409 to 0.8544) with the ratio for $^{208}Pb/^{206}Pb$ being 2.0870 (range, 2.0782 to 2.0962). There are currently few published data with which to compare these results. The isotopic composition of lead seems to fall into two groups of 0-60 and >61 µg/g (Figure 3), reflecting presumably the local lead and imported lead end members. As discussed below, most of the samples were diagenetically contaminated with soil lead and the concentrations observed pertained more to soil lead than to bone lead at the time of burial. This would suggest that the soil Pb is isotopically quite inhomogeneous, and the grouping points to extensive contamination of soils in the cemetery with lead (see below).

DISCUSSION

Diagenetic effects on Pb content

It is evident from various aspects of the data that the content and isotopic composition of the human bones from Isola Sacra have been affected by *post mortem* diagenetic effects. We can see this, for example by considering data for animal bones from the site. Intuitively, one would expect higher concentrations of lead in bones of carnivorous house pets (dogs) or garbage scavengers (pigs) compared to those of strictly herbivorous sheep, cows and horses. The fact that comparable and high levels of lead are found in bones irrespective of all of the animal species suggests that all types of bones have been affected by diagenetic contamination with lead from soils. Average concentration of lead in Isola Sacra soil has been reported to be 77 ± 46 μg/g (Grupe, 1999), implying that the soil can be an important source of bone lead contamination. The animal bones were probably refuse from ceremonial meals held at the cemetery and were probably discarded in such a way that they were in intimate contact with soil matrix (see Table 2).

The 77 ± 46 μg/g value for lead in cemetery soil is quite high compared to the global average value of 12 μg/g for soils (Nriagu, 1978), and xxx μg/g for Italian soils. Excess lead in the cemetery soils most likely was artificially introduced, the use of lead for ossuaries and ritual purposes being common in ancient times (Nriagu, 1983). Input from anthropogenic sources is consistent with the fact that samples with the highest lead levels were those buried directly in the soil and therefore likely to be most strongly contaminated with the imported lead. Furthermore, the samples sandy soils or "sabbia" (most likely to be impacted by mobilization of artificial lead) show the largest dispersion in isotopic ration of lead.

The necropolis of Isola Sacra contains a wide variety of burial structures including simple interment in sandy soil, wooden coffins, brick layers ("cappucina"), ceramic vessels ("amphorae"), terracotta sarcophagi, and monumental tombs containing both single and multiple burials (Sperduti, 1995). The concentrations of lead in three principal burial environments, namely bare soil soil with some protection such as wood or brick, and monumental tombs, are shown in Figure 4. Bones interred in soils had the widest variation and highest average lead concentration (22 ± 18 μg/g) while those in monumental tombs had the lowest average concentration (8.7 μg/g) and variation. Occasional waterlogging of the graves due to the location of the cemetery near an ancient seaport sealevel in a floodplain would have facilitated the diagenetic exchange of lead between the soil and bones. The isotopic composition of lead in bones from soils also shows a much wider variation compared to samples from the other two burial types (Figure 5). The similarity in average lead levels of human and animal bones buried in soils is rather remarkable, and provides a strong evidence for post-burial additions of lead to the bones. Previous attempts to estimate the difference in modern and ancient bone lead levels have been bedeviled by the problem of post-mortem diagenesis and contamination in the burial environment (Waldron, 1981; Grandjean, 1988; Patterson et al., 1991; Hedges and van Klinken, 1995). Most of the reported lead levels in archaeological bone samples from unprotected burial arrangements may be considered to be ureliable. It should be noted that the concentrations of lead in a number of bone samples are similar to or slightly higher than those of the soil suggesting that changes in bone lead content can occur by (a) direct uptake of lead from soil solutions in contact with the bone, and (b) diagenetic removal of bone material (such as collagen) resulting in enrichment of lead in the residue (Patterson et al., 1991). It is impossible to tell which of these to processes was dominant in Isola Sacra burial environment on the basis of our data.

The preservation of bones at Isola Sacra has been categorized into "normal" (similar to fresh bone), "focalized" (with focal tunnels), "amorfo" (advanced stage of focalized category with less dense tunnels and lacking microstructures), and "mineralized" (organic material completely removed but still possible to recognize tissue morphology) (Savore, 1996). Previous studies have generally found no relationships between the burial conditions and histological categories (Grupe, 1999). It is generally believed that "normal" bones are less liable to diagenetic changes than decomposed samples, and several studies claim that "normal" samples were used to minimize any effects of post-mortem changes (Waldron, 1981; Jaworowski et al., 1985). Our data show that normal bones have higher lead levels (54 µg/g) than focalized samples (26 µg/g). Because of the small number of samples in the histological categories, not much should be made of this difference. Our results are consistent with the observation by Grupe (1999) that the degree of histological preservation is unrelated to the lead contamination and that the best preserved samples can show a high variability in lead contents.

Pb in bones from protected environments

When we consider the data for bones from protected sites (coffins, cappucina and amphorae) we observe several characteristic relationships between Pb composition and independent biological features of the bone. This suggests that the observed variations represent primary (pre mortem) characteristics of the bones, as follows: <u>Age dependent change in lead concentrations</u>. Average concentrations of bone lead in the 5-20, 20-40 and >40-year old groups were found to be 6.5, 4.4 and 18 µg/g, excluding the anomalously high value for one person. The slight decrease in bone level in the 20- to 40-year old group can be attributed to the effect of immigration of young workers from provinces where the lifestyles were less predisposing to lead exposure. <u>Age dependent differences in isotopic composition of bone lead</u> (Figure 6). The isotopic composition of 5- to 20-year olds is less variable and distinct from those for the other age groups, and presumably reflects the local isotopic signature determined by environmental and socio-cultural factors. The diversity in culture and backgrounds of the 20- to 40-year population is reflected by the wide variation in the isotopic composition of their bone lead. The isotopic composition of people older than 40 years (see Figure 6) can be considered to be a mixture of the signatures of the two younger population groups. <u>Gender difference in bone lead levels</u>. A significant difference was found between the bone lead concentrations for males (13 μg/g) and females (8.2 μg/g). Although gender differences in traditional eating and drinking habits among the Roman people had disappeared by the 2nd Century AD (Nriagu, 1983), the gender differences may related to the fact that women were excluded from trade guilds and thus partially protected from other dangerous occupations (Meiggs, 1973). The suggestion that bones protected in monumental tombs are uncontaminated thus depends not only on the experimental results but also on the fact that the data fit the expected pattern of lead exposure and burden in the particular population.

From these observations and the previous discussion on samples buried at unprotected sites in soils, we must conclude that many if not all of the latter samples from Isola Sacra have experienced significant uptake of Pb with highly variable isotopic composition. Since we are principally interested here in the *pre mortem* Pb concentrations of the individuals buried here, we will focus our our subsequent discussion on the analyses of bones from protected site: coffins, cappucina or amphorae. Note However that these samples constitute only 18 of the total 98 samples analysed. In a future study, we intend to select only bones from protected environments for analysis. While only c. 20% of the present series of analyses appear to reflect lifetime Pb uptake, we believe that this is the first study of Pb in Roman bones in which we can assure the authenticity of the data. One consequence of our exclusion of the data for bones buried in unprotected sites is that we main be inadvertently contributing a bias to the data, by excluding persons whose burial sites were relatively modest and in most cases lacked any indications of their social status. At present we have no way in which to correct for such bias, if it exists.

Our overall results (not selected for burial type) are generally consistent with the data that have been reported for bones from a number of Roman cemetery populations: 1.8-93 μg/g for various sites in Italy (Aufderheide et al., 1992), 1-22 μg/g for samples from Roman cemeteries at Maule and Chiragan, France (Jaworowski et al., 1985), and 35-495 for Romano-British cemeteries at Cirencester (Waldron, 1976). The three-fold difference in bone lead concentrations between the Roman rich (155 μg/g) and poor (50 μg/g) populations reported by Gilfilan (1991) may not be directly relevant to the present data for egalitarian middle class population. Moreover, the provenance of Gilfilan's (1991) samples were poorly documented, and the handling of his samples left a lot to be desired.

Reported average lead concentrations in pre-technological adult bones include 0.6 μg/g for sites in Nubia (Grandjean et al., 1979), 1.1 μg/g in Peru (Ericson et al., 1979), 0.65 μg/g in New Mexico (Ericson et al., 1991), <1.0 μg/g in Pennsylvania (Becker et al., 1968), 0.2 μg/g in Greenland (Grandjean, 1988), <0.1 μg/g in France (Jaworowski et al., 1985), <0.2 μg/g in Denmark (Grandjean, 1988), and 0.58 μg/g in Japan (Hisanaga et al., 1988). The mid-range of these values which have been reported from various parts of the world is about 0.5 μg/g, and can be considered an approximate global background level for lead in human bones. By comparison, the average lead concentration in the 22 bones from protected monumental tombs is 10±6.8 μg/g, or about 20-fold higher than the background value. The average bone lead level is comparable to values that have been reported for many contemporary populations, such as 4.5 μg/g in western Japan (Hisanaga et al., 1988), 7.1 μg/g in Taiwan (Kuo et al., 2000), 18 μg/g in Tenerife (Arnay-de-la-Rosa et al., 1998), and 22 μg/g in Greater Boston, Massachusetts (Cheng et al., 1998). The bones clearly provide a silent witness to the fact that the people of Portus were exposed to substantial amounts of lead in their lifetime. It should be noted that pre-industrial bones buried in soil can show low Pb levels. This supports our suggestion that the high Pb levels for soils in the Isola Sacra (as well as in the bones) were the result of extensive contamination of the burial site with lead from processing of lead within the cemetery and possibly from lead manufactories located outside the burial grounds.

Societal Implications of observed Pb distributions at Isola Sacra

To address the lead exposure in proper context, one has to consider the character and social fabric of people who were buried in Isola Sacra. This cemetery is located between the river Tiber and the "canale di Fiumicino" just off the road between Portus and Ostia. Portus was a port of Rome first started by Claudius in 41 AD and completed by Trajan around 100-112 AD (Garnsey, 1999). Both Portus (a sea harbor) and Ostia (a river port) were connected by a complex of basins and canals and served to maintain an uninhibited flow of good, especially grain and other vital foodstuffs, into the metropolis of Rome. The cemetery population at Isola Sacra would have been representative of the people who lived in Portus and Ostia. The monumental work by Meiggs (1973) provides the following excerpt on social construct and lifestyles of the people of Ostia (and Portus):

"Free-born citizen, freedman, and slave had their separate legal status, but social distinctions were often blurred. A verna brought up in a rich household probably had as much affection and more material comfort than a son of a free citizen living in a crowded tenement. A rich freedman who became president of a builder's guild was acceptable in society as a poor man who could trace his descent from the Republic. A weakening of class barrier is to be expected in a trading city and it is clear that, in the second century at least, trading interests dominated Ostia. Trade was the natural outlet for ambition and dominated the social atmosphere. …But it would be a mistake to think of Ostia as a town where life was oppressed by hard work, and men thought of nothing but the profits and trade. The large number of sets of public baths show that hard work was balanced by recreation in plenty; and Ostia had hher bons viveurs. C. Domitius Primus in his epitaph made no attempt to disguise his standard: "I have lived on Lucrine oysters and many a time drunk Falernian. Women and wine and bathing have grown old with me through the years"….. But trade was the dominant interest and this is clearly reflected in the scratchings on house walls which bring us closer than the formal language of funerary inscriptions to the daily life of the lower class. In striking contrast to Pompeii, there are no Virgilian tags, and no literary quotations. But far more common are a series of numbers, rough accounts, records of debts and dates. Most striking of all is the number of ships scratched on the walls, from large merchantmen to small rowing boats. Some of these sketches are roughly drawn but many of the merchantmen are drawn in considerable detail, showing close familiarity with technicalities of the riggings (Meiggs, 1973, p.230-231).

The people in the port cities of Portus/Ostia were likely to be exposed to lead both at work and in their homes. Lead was a vital commodity that was required in massive amounts in Rome (Patterson, 1972; Nriagu, 1983). Little is known about the local dispersion of imported lead bars and ingots that were landed in Pontus/Ostia. It probably made good economic sense to use the lead to make commercial products in the port city rather than haul the heavy bars and ingots over land to other places. Portus and Ostia were cities for craftsmen and traders who would not have passed up an opportunity to benefit from the massive lead import. A focal point of commercial activity for the community revolved around the ship: "Most striking of all [the inscriptions] is the number of ships scratched on the walls, from large merchantmen to small rowing boats. Some of these sketches are roughly drawn but many of the merchantmen are drawn in considerable detail, showing close familiarity with technicalities of the riggings" (Meiggs, 1973, p.230-231). Lead was extensively used for naval purposes in ancient times -- as paint coatings, solder on metal joints, weights on ends of oars and keels of ships (to maintain balance), sheets on hulls of ship (protects against corrosion and encrustation), plumb line, anchor, etc (Nriagu, 1983). The number of the local population handling lead in goods and services to the shipping companies conceivably was large. Inscriptional evidence point to the fact that manufacturing of lead pipes (and lead sheets) was carried on by many people in the two cities (Meiggs, 1973). The lead also went to fabrication of various consumer products (vessels, vases, kitchenware, statues, figurines, stationary, etc) and preparation of a wide assortment of lead compounds and lead alloys (Nriagu, 1983). Most of the work on lead was done as a cottage industry which would exposed the worker and his family to lead and contaminated the immediate neighborhood with lead. One therefore suspects that a substantial number of workers and their families in Pontus/Ostia were occupationally exposed to lead.

Like today, the circumstances under which the people of Portus/Ostia could have been exposed to lead from non-occupational sources were legion, often bizarre and sometimes dramatic. The principal exposure routes would have included lead-containing cosmetics, drinking water (from lead pipe, water tanks and water containers), foods (lead compounds were used as preservatives and sweetening agents), wines (Roman wines could be contaminated with lead in over a dozen different ways), beverages (juices boiled or mulled in leaden or pewter cauldron), as well as saturnine drugs and elixirs (see Nriagu, 1983). A major source of lead in the diet would have come from the consumption of *sapa* , a concentrated syrup prepared by slowly simmering grape juice with herbs and spices in a lead-lined cauldrons (Patterson *et al.*, 1987). Sapa was widely used as a preservative for wine and as a flavor enhancer for poor quality wine (Gilfillan, 1965; Waldron, 1972). Sapa was also used in soups, medicinal potions, and in the preparation of drinks (Gilfillan, 1965). Patterson *et al.* (1987) prepared sapa in a lead cauldron following Roman period recipes and observed that the product contained up to 1000 µg/g Pb.

Unusual routes of exposure would have included lead coins (when handled excessively, mouthed or inadvertently swallowed), yarns treated with lead salts as make weight, children's toys made of lead, candleholders, wickholders and candlewicks made of lead or pewter, lead and pewter cups, pans and kitchenware, etc (Nriagu, 1983).

The funerary population at Isola Sacra belonged to the age when lead was extensively used and the people were involved in occupational pursuits and lifestyles that would have exposed many of them to lead. Their skeletal remains bear a silent witness to this extensive contact with lead. The large variation in the bone lead levels is very consistent with lead exposure from a wide variety of sources. This study shows that exposure to lead was not limited to Roman aristocracy but was pervasive in all the social classes. It is interesting that elevated levels of lead were found among both men and women. The available evidence clearly show that the women of Ostia enjoyed high social standing: "We find them owning slaves and house property; there are two women among the owners of workshops for making lead pipes. They build tombs and sell sites to others. They are commemorated in the most affectionate terms as wives, mothers, sisters, and daughters and there is no trace in the cemetery inscriptions that girls received less affection than boys. The public funerals accorded to women reflect a general respect for their importance in the family life .. Women had no place in the trace guilds and the seviri Augustales were confined to men" (Meiggs, 1973, p.229). Apparently, their emancipation exposed them to the risk of lead poisoning.

Estimated blood lead levels

Blood lead level has become the gold standard as a biomarker of lead exposure and health effects. A number of biokinetic models have been published relating bone lead to blood lead concentrations (Erkkila et al., 1992; Leggett, 1993; Gerhardsson et al., 1993; Roels et al., 1995; Roy et al., 1997; Fleming et al., 1997; Mason, 2000).

Average (bone lead)/(cumulative blood lead) ratios derived in these models vary from 0.024 (Erkkila et al., 1992) to 0.066 (Roels et al., 1995) with an average value estimated to be 0.043 (Mason, 2000). Assuming that lead metabolism in modern people are similar to that of ancient Romans, the biokinetic model can be used to estimate the blood lead levels corresponding to the bone lead from monumental tomb structures. The life expectancy for the cemetery population of Isola Sacra has been estimated to be 23.3 years (Sperduti et al., 1999). From average bone lead concentration of 10 µg/g and assuming (bone lead)/(cumulative blood lead) ratio of 0.043, the average blood lead level for the Isola Sacra population is estimated to be about 10 µg/dL (range 0.89 to 36 µg/dL). The blood lead levels for the different age groups are similarly estimated to be 12 µg/dL, 3.4 µg/dL and <10 µg/dL respectively for the 5-20, 20-40 and >40-year age groups. These data are comparable to blood lead levels that have been reported in many modern urban environments (NAS, 1996; Nriagu et al., 1996; Tong et al., 2000). The health effects of such blood lead levels in an ancient population are difficult to ascertain; the possibility that the inhabitants of Portus/Ostia with the highest levels of lead in their blood experienced symptoms of lead poisoning cannot be ruled out. One of the highest bone lead concentrations observed was the 75 µg/g for a male 5-20 years old; thid value would be equivalent to blood lead level of about 116 µg/dL. Furthermore, the $^{207}Pb/^{206}Pb$ (= 0.8508) and $^{208}Pb/^{206}Pb$ (=2.094) ratios for this person were quite different from those of other bones, suggesting that the person probably died as a result of consumption of medication containing lead rather than from normal dietary and environmental exposures. Saturnine drugs were widely prescribed and used in Roman times.

Source of the lead

The isotopic composition of lead can be used to identify the principal sources of the lead to which the cemetery population of Isola Sacra was exposed. The isotopic ratios of bone lead from protected monumental tombs fall within a fairly narrow range: about 0.842 - 0.854 for $^{207}Pb/^{206}Pb$ and 2.08-2.10 for $^{208}Pb/^{206}Pb$ (Figure 7). The isotopic composition of the bone lead is unlike that of any ores (Figure 7) or rocks (Table 3) in Italy , implying that most of the lead used in Portus/Ostia was imported. It should, however, be noted that very little information is available on isotopic composition of soil lead in the region. Reported isotopic compositions of lead in various types of rocks in Italy (see Table 3) would suggest that the isotopic signature of local soils may be significantly different from that of Isola Sacra bone lead, however.

The isotopic compositions of lead from principal mining districts in Europe and the Middle East that were exploited by Imperial Rome are compared with the typical range for the Isola Sacra lead (Figure 7). In general, the isotopic composition of the bone lead is different from those of lead ores from ancient mines of Sardinia and Spain (Stos-Gale et al., 1995), the Aegean Islands (Stos-Gale et al., 1996) and other places (Figure 7). There is however a similarity in the isotopic ratios of bone lead and ore leads from Britain (including Wales, Cumbria, Shropshire, Mendip/Bristol, Penniness, Devon and Cornwall and Alderley Edge mining districts; Rohl, 1996), Bulgaria (northwest region, west Rhodope and Panagyurski regions; Stos-Gale et al., 1998), Turkey (Kure, Trabzon and Artvin areas; Sayre et al., 2001) and France (Guen et al., 1992). The data suggests a rather heterogeneous origin for lead used by the Isola Sachra population. Studies in ancient economic history often claim that the largest supplies of lead used in Rome came from Spain, central Europe and North Africa (Nriagu, 1983). Our data tends to suggest that the importance of these sources to the local economy of Portus/Ostia, especially during the second and third centuries AD, may be over-estimated.

The close similarity of the isotopic composition of Isola Sachra bone lead with that of the Roman water pipes from Pompeii (Boni et al., 2000) is rather interesting. The similarity suggests that the same sources supplied lead to many other Roman communities during the time of the funerary population. Furthermore, The production and fabrication of lead pipes as a cottage industry and the use of the pipes in local water supply systems would have been a significant sources of lead exposure in a commercial city like Portus/Ostia.

The homogenization of lead isotopes among the peoples of Portus/Ostia, which included a large immigrant population, was rather remarkable and consistent with recent reports on lead exchange in bones. The turnover rates for lead in trabecular bones have been estimated to be ~6-8% per year (Rabinowitz, 1991; Gulson and Gillings, 1997), suggesting that the immigrants would have exchanged most of their original lead with local lead in Portus/Ostia in approximately 12-15 years. By contrast, the isotopic composition of lead in the bones from unprotected (soil) burials was much more inhomogeneous.

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REFERENCES

Aufderheide, A.C., G. Rapp, L.E. Wittmers, J.E. Wallgren, R. Macchiarelli, G. Fornaciari, F. Mallegni and R.S. Corruccine. 1992. Lead exposure in Italy: 800 BC - 700AD. Internat. J. Anthrop. 7: 9-15

Al-Bassam, K.S., J. Hak and D. H. Hatkinson. 1982. Contribution to the Origin of the Serguza Lead-Zinc-Pyrite Deposit, Northern Iraq. *Mineralium Deposita.* 17: 133-149.

Amov, B., V. Arnoudov, M. Pavlova, P. Dragov, T. Baldjieva and S. Evstatieva. 1981. Lead isotope data on the Paleozoic granitoids and ore mineralization from the Western Balkan Mountains and the Trân District (West Bulgaria). *Geologica Balcanica.* 11: 3-26.

Andersen, T. and H. F. Grorud. 1998. Age and lead isotope systematics of uranium-enriched cobalt mineralization in the Modum complex, South Norway Implications for Precambrian crustal evolution in the SW part of the Baltic Shield. *Precambrian Research.* 91: 419-434.

Angelucci S., I. Baldassarre, I. Bragantini, M. G. Lauro, V. Mannucci, A. Mazzoleni, C. Morselli and F. Taglietti. 1990. Sepolture e riti nella necropolis dell'Isola Sacra. *Bollettino di Archeologia*. 5-6:50-113.

Arnay-de-la-Rosa, M., E. Gonzalez-Reimers, Y. Velasco-Vazquez, L. Galindo-Martin, E. Delgado-Ureta, F. Santolaria-Ferdinandez, and N. Berros-Lopez. 1998. Comparison of bone lead in pre-Hispanic, 18th centuryh and modern population of Tenerife. Sci. Total Environ. 209: 107-111

Bacon, J.R., M. L. Berrow and C. A. Shand. 1995. The use of isotopic composition in field tudies of lead in upland Scottish soils (UK). *Chemical Geology.* 124: 125-134.

Baldassarre I. 1980. La necropolis dell'Isola Sacra. *Archeologia Laziale*. 3: 126-128.

Baldassare I. 1984, Una necropolis imperiale romana: proposte di lettura. *Archeologia e Storia Antiaca*. 6: 141-149.

Becker, R.O., J.A. Spardaro, and E.W. Berg. 1968. The trace elements of human bone. J. Bone Joint Surg. 50: 326-330

Bondioli, L. and Macchiarelli, R. 1999. The 'Isola Sacra Project': In *Osteodental Biology of the People of Portus Romae (Necropolis of Isola Sacra, 2nd-3rd cent. AS) Part I – Enael Microstructure and Developmental defects of the Primary Dentition*, CD series: digital Archives of Human Paleobiology. I. Milano, Italy.

Boni, M., Di Mario, G., Frei, R. and Villa, M. 2000. Lead isotopic evidence for a mixed provenance for Roman water pipes from Pompei. Archaeometry 42: 201-208

Caggianelli, A., Del Moro, A., Paglionico, A., Piccarreta, G., Pinarelli, L. and Rottura, A. 1991. Lower crustal granite gneiss connected with chemical fractionation in the continental crust of Calabria (southern Italy). Eur. J. Mineral. 3: 159-180

Calza G. 1940. *La Necropoli del Porto di Roma nell'Isola Sacra*. Roma: Istituto Poligrafico dello Stato.

Chen, Y., W.C. Willett, J. Schwartz, D. Sparrow, S. Weiss and H. Hu. 1998. Relation of nutrition to bone lead and blood lead levels in middle-age to elderly men. Am J. Epidemiol. 147: 1162-1174

Clocchiatti, R., Del Moro, A., Gioncada, A., Joron, J.L., Mosbah, M., Pinarelli, L. and Sbrana, A. 1994. Assessment of a shallow magmatic system: the 1888-90 eruption, Volcano Island, Italy. Bull. Volcanol. 56: 466-486

Del Moro, A., Gioncada, A., Pinarelli, L., Sbrana, A. and Joron, J.L. 1998. Sr, Nd, and Pb isotope evidence for open system evolution at Volcano, Aeolian Arc, Italy. Lithos 43: 81-106

Doe, B.R. 1970. Lead Isotopes. Springer-Verlag New York ·Heidelberg ·Berlin.

Ericson, J.E., D.R. Smith, and Flegal, A.R. 1991. Environ Health Perspect. 93: 217-223

Erkkila, J., R. Armstrong, V. Riihimaki, et al. 1992. In-vivo measurements of lead in bone at four anatomical sites: Long-term occupational exposure and consequences of endogenous exposure. Br. J. Indust. Med. 49: 631-644

Ferrera, G., Garavelli, A., Pinerelli, L., Vurro, F. Lead isotope composition of the sublimates from the fumaroles of Vulcan (Aeolian Islands, Italy): inferences on the deep fluid circulation. Bull. Vulcanol. 56: 621-625

Fleming, D., Boulay, N. Richard, et al. 1887. Accumulated body burden and endogenous release of lead in employees of a lead smelter. Environ. Health Perspect. 105: 224-233

Gale, N.H, and Stos-Gale, Z.A. 1982. Bronze Age Copper Sources in the Mediterranean: A New Approach. *Science.* 216: 11-19.

Garnsey P. 1988. *Famine and Food Supply in the Graeco-Roman World. Responses to Risk and Crisis*. Cambridge: Cambridge University Press.

Garnsey, P. 1999. The People of Isola Sacra: In *Osteodental Biology of the People of Portus Romae (Necropolis of Isola Sacra, 2nd-3rd cent. AS) Part I – Enael Microstructure and Developmental defects of the Primary Dentition*, CD series: digital Archives of Human Paleobiology. I. Milano, Italy.

Gilfillin, S. C. 1965. Lead poisoning and the fall of Rome. *Journal of Occupational Medicine.* 7: 53-60.

Gilfillan, S.C. 1991. Rome's Ruin by Lead Poisoning. Wenzel Press, Long Beach, CA

Grandjean, P. 1988. Ancient skeletons as silent witness of lead exposures in the past. CRC Crit. Rev. Toxicol. 19: 11-21

Grupe, G. 1999. Paleodiet and diagenesis of Isola Sacra, 1st-3rd Century AD. A trace element study of skeletal finds. Manuscript to be published in: Osteodental Biology of the People of Portus Romae (Necropolis of Isola Sacra, 2nd-3rd cent. AS) Part I – Enael Microstructure and Developmental defects of the Primary Dentition, CD series: digital Archives of Human Paleobiology. Milano, Italy.

Guen, M.L., J. L. Lescuyer and E. Marcoux. 1992. Lead-isotope evidence for a Hercynian origin of the Salsigne gold deposit (Southern massif Central, France). *Mineralium Deposita.* 27: 129-136.

Gulson, B.L. and B.R. Gillings. 1997. Lead exchange in teeth and bone -- a pilot study using stable lead isotopes. Environ. Health Perspect. 105: 820-824

Haggerty, R., P. Budd, B. Rohl and N. H. Gale. 1996 (a). Pb-isotope evidence for the role of Mesozoic basins in the genesis of Mississippi Valley-type mineralization in Somerset, UK. *Journal of the Geological Society*. London. 153: 673-676.

Haggerty, R., B. M. Rohl, P. D. Hudd and N. H. Gale. 1996 (b). Pb-isotope evidence on the origin of the West Shropshire orefield, England. *Geological Magazine.* 133(5) 611-617 .

Hedges, R.E.M. and G.J. van Klinken, guest editors. 1995. Bone diagenesis. J. Archaeol. Sci. 22 (2)

Hisanaga, A. Y. Eguchi, M. Hirata and N. Ishinishi. 1988. Lead levels in ancient and contemporary Japanese bones. Biol. Trace Element Res. 16: 77-85

Jaworowski, Z., F. Barbbalat, C. Blain and E. Peyre. 1985. Heavy metals in human and animal bones from ancient and contemporary France. Sci. Total Environ. 43: 103-125

Kuo, H.W., S.M. Kuo, C.H. Chou and T.C. Lee. 2000. Determination of 14 elements in Taiwanese bones. Sci. Total Environ. 255: 45-54

Leggett, R.W. 1993. An age-specific kinetic model of lead metabolism in humans. Environ. Health Perspect. 101: 598-616

Mason, H.J. 2000. A biokinetic model for lead metabolism with a view to its extension to pregnancy and lectation: I. Further validation of the original model for non-pregnant adults. Sci. Total Environ. 246: 69-78

Meiggs, R. 1972. Roman Ostia. Clarendon Press, Oxford

Mudrinic, C. and T. Serafimovski. 1992. Lead, sulphur, oxygen and carbon isotopes in the Zletovo ore field (Eastern Macedonia). *Geologica Balcanica.* 4: 39-48.

Howson, C.P., M. Hernandez-Avila, and D.P. Rall, Editors. 1996. Lead in the Americas. National Academy of Sciences Press, Washington, D.C.

Nriagu, J. 1983. Lead and Lead Poisoning in Antiquity. A Wiley-Interscience Publication.

Nriagu, J.O. 1985. Historical perspectives on the contamination of food and water with lead. In: Dietary and Environmental Lead: Human Health Effects (K.R. Mahaffey, Editor), Elsevier, Amsterdam

Nriagu, J.O., M.L. Blankson and K. Ocran. 1996. Childhood lead poisoning in Africa: a growing public health problem. Sci Total Environ. 181: 93-100

Pinarelli, L. 1991. Geochemical and isotopic (Sr, Pb) evidence for crust-mantle interaction in acidic melts -- The Tolfa-Cerveteri-Manziana volcanic complex (central Italy): a case study. Chem. Geol. 92: 177-195

Pinarelli, L., Boriani, A. and Del Moro, A. 1993. The Pb isotopic systematics during crustal contamination of subcrustal magmas: the Hercynian magmatism in the Serie dei Laghi (southern Alps, Italy). Lithos 31: 51-56

Patterson, C.C. 1972. Silver stocks and losses in ancient and medieval times. Econ. Hist. Rev. 25: 205-235

Patterson CC, H. Shirahata and J. E. Ericson. 1987. Lead in ancient human bones and its relevance to historical developments of social problems with lead. *Sci Tot Environ.* 61: 167-200.

Perette, A. and V. Köppel. 1986. Geochemical and lead isotope evidence for a mid-ocean ridge type mineralization within a polymetamorphic ophiolite complex (Monte del Forno, North Italy/Switzerland). *Earth and Planetary Science Letters.* 80: 252-264.

Pettke, T. and R. Frei. 1996. Isotope systematics in vein gold from Brusson, Val d'Ayas (NW Italy). *Chemical Geology.* 127: 111-124.

Rabinowitz, M.B. 1991. Toxicokinetics of bone lead. Environ. Health Perspect. 91: 33-37

Roels, H., J. Konings, G. Green, D. Bradley, D. Chettle and R. Lauwerys. 1995. Time-integrated blood lead concentration is a valid surrogate for estimating the cumulative lead dose assessed by tibial lead measurement. Environ. Res. 69: 75-82

Rohl, B.M. 1996. Lead isotope data from the Isotrace Laboratory, Oxford: Archaemetric database 2, galena from Britain and Ireland. Archaeometry 38: 165-180

Rottura, A., Del Moro, A., Pinarelli, L., Petrini, R., Peccerillo, A., Caggianelli, A., Bargossi, G.M. and Piccarreta, G. 1991. Relationships between intermediate and acidic rocks in the orogenic granitoid suites: petrological, geochemical and isotopic (Sr, Nd, Pb) data from Capo Vaticano (southern Calabria, Italy). Chem. Geol. 92: 153-176

Sakamoto, M. 2000. Lead concentrations and isotopic compositions from Isola Sacra, Italy. Unpublished Master's Thesis, School of Public Health, University of Michigan, Ann Arbor, MI

Sayre, E.V., Joel, E.C., Blackman, M.J., Yener, K.A. and Ozbal, H. 2001. Stable lead isotope studies of Black Sea Anatolian ore sources and related bronze age and Phrygian artifacts from nearby archeological sites. Archaeometry 43: 77-115

Stos-Gale, Z., Gale, N.H., Houghton, J. and Speakman, R. 1995. Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry database 1, ores from the Western Mediterranean. Archaeometry 37: 407-415

Stos-Gale, Z., Gale, N.H.and Annetts, N. 1996. Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry database 3, ores from the Aegean, Part 1. Archaeometry 38: 381-390

Stos-Gale, Z., Gale, N.H., Annetts, N., Todorov, T., Lilov, P., Raduncheva, A. and Panayotov, I. 1998. Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry database 5, ores from Bulgaria. Archaeometry 40: 217-226

Sundblad, K., J. Mansfeld and M. Sarkinen. 1997. Palaeoproterozoic rifting and formatin of sulphide deposits along the southwestern margin of the Svecofennian Domain, southern Sweden. *Precambrian Research.* 82: 1-12.

Sperduti A. 1995. *I Resti Scheletrici Umani della Necropoli di Eta Romano-Imperiale di Isola Sacra* (*I-III sec. d.C.*): *Analisi Paleodemografica*. PhD Thesis in Anthropology. Roma: Universita di Roma 'La Sapienza'.

Sperduti, A., L. Bondioli, T.L. Prowse, F. Salomone, D. Yang, R. Hoppa, S.R. Saunders and R. Macchiarelli. 1999. The juvenile skeletal sample of Imperial Roman site at Portus Romae.

Testaguzza, O. 1964. The port of Rome. *Archaeology*. 17: 173-179.

Tong, S., von Schirnding, Y.E. and T. Prapamontol (2000). Environmental lead exposure: a public health problem of global dimensions. Bull. World Health Org. 78: 1068-1077

Waldron, H.A. (1981). Postmortem absorption of lead by the skeleton. Am. J. Phys. Anthrop. 55: 395-398

Waldron, T. 1988. The Heavy Metal Burden in Ancient Societies. In: Gisela Groupe and Bernd Herrann (Eds.) *Trace Elements in Environmental History*. Springer-Verlag. 125-133.

Waldron, T. and C. Wells. 1979. Exposure to lead in ancient populations. Medicine & History, Series V, Vol 1: 102-115

Waldron, T., A. Mackie and A. Townsend. 1976. The lead content of some Romano-British bones. Archaeometry 18: 221-227

Table 1. Lead concentrations and isotopic compositions of rinse solution for Human and animal bone samples.

Sample Number/Type	^{207}Pb / ^{206}Pb Ratio	± relative Error (%)	^{206}Pb / ^{206}Pb Ratio	± relative error (%)	Pb conc µg / g
Human Bones					
Rinse 40	0.84667	0.108	2.0837	0.107	0.30
Rinse13	0.83910	0.108	2.0645	0.107	0.04
Rinse 7	0.84296	0.002	2.0715	0.023	0.08
Rinse 12	0.84513	0.002	2.0801	0.023	0.40
Average	0.84346	0.055	2.0750	0.065	0.20
standard deviation	0.00254	0.048	0.0067	0.037	0.13
Max	0.84667	0.108	2.0837	0.107	0.40
Min	0.83910	0.002	2.0645	0.023	0.04
Animal Bones					
Rinse 1					0.06
Rinse 2					0.37
Rinse 3					0.15
average					0.19
standard deviation					0.16
max					0.37
min					0.06

Table 2 Lead concentrations in animal bone samples

Sample Number	**Animal**	**Excavation Site**	**Pb conc (µg / g)**
1	horse, donkey		5.33
2	ox, cow		27.92
3	horse		7.65
4	Pig		6.82
5	Pig	dark soil	29.26
6	dog family	found at the side of a road	26.92
7	sheep	found at the side of a road	33.76
8	Pig	found at the side of a road	44.75
9	ox, cow	light soil	24.99
10	ox, cow	black stratum / layer	1.29
11	ox, cow	quadrant, dark stratum / layer	17.56
Average			20.57
Mediam			24.99
standard deviation			13.85
Max			44.75
Min			1.29

Table 3. Average isotopic compositions of lead in rocks from various parts of Italy

Rock type and location	**$^{207}Pb/^{206}Pb$**	**$^{208}Pb/^{206}Pb$**
Tolfa-Cerveteri-Manziana volcanic complex of central Italy	0.8296	2.083[a]
Intermediate and acidic rocks in orogenic granitoid suites at Campo Vaticano, southern Calabria	0.8520	2.102[b]
Granulite facies rocks of Calabria, southern Italy	0.8559	2.137[c]
Fumaroles and sublimates of Vulcano, Aeolian Islands	0.8100	2.031[d]
Shallow magmatic system, 1888-1890 eruption, Aeolian Islands	0.8097	2.0301[e]
Hercynian magmatism in the Serie dei Laghi, southern Alps	0.8598	2.109[f]
Aeolian Arc at Vulcano	0.8106	2.033[g]

(a). Pinarelli, 1991

(b). Rottura et al., 1991

(c). Caggianelli et al., 1991

(d). Ferrara et al., 1995

(e). Clocchiatti et al., 1994

(f). Pinarelli et al., 1993.

(g). Del Moro et al., 1998.

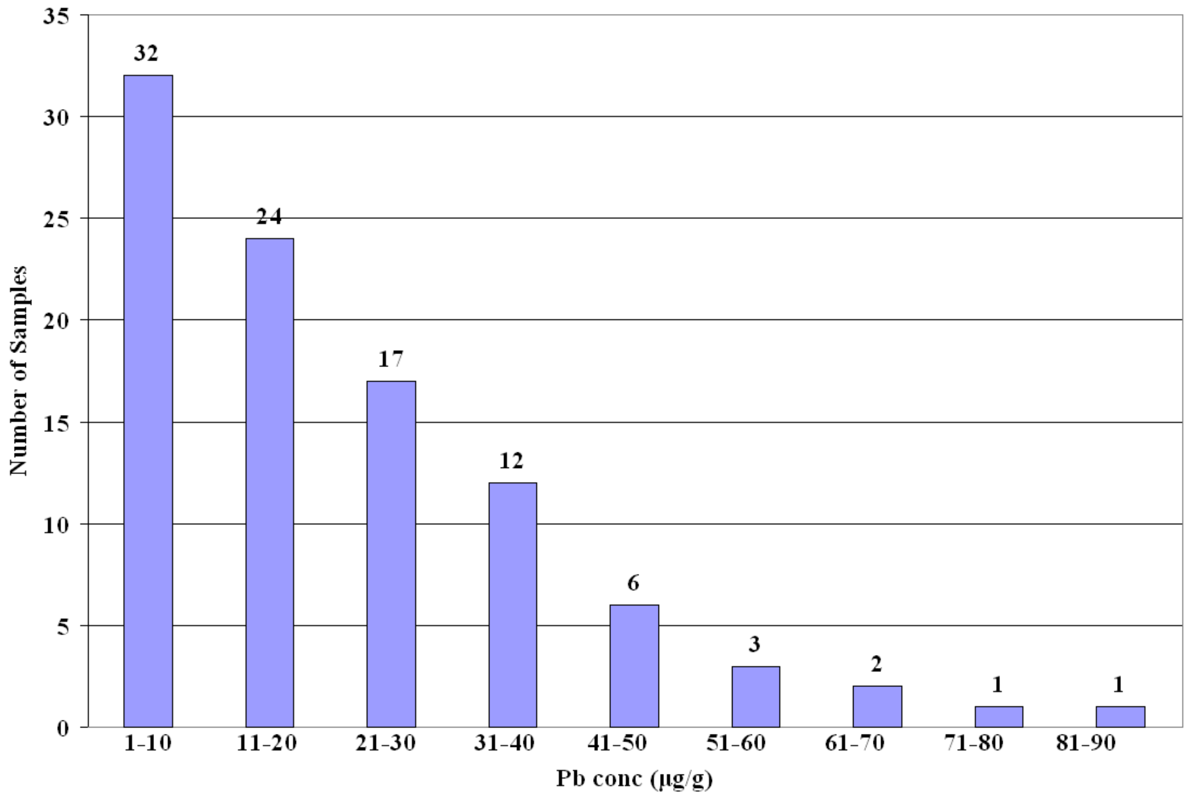

Figure 1. Histogram of bone lead levels in sample from Isola Sacra.

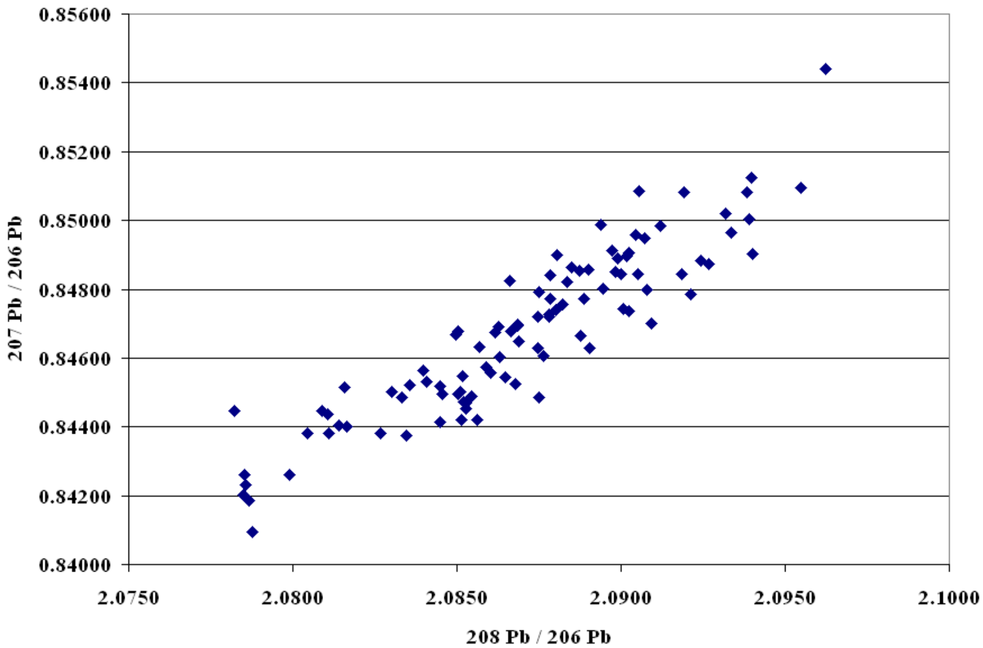

Figure 2. Ratios of $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ for the bone samples

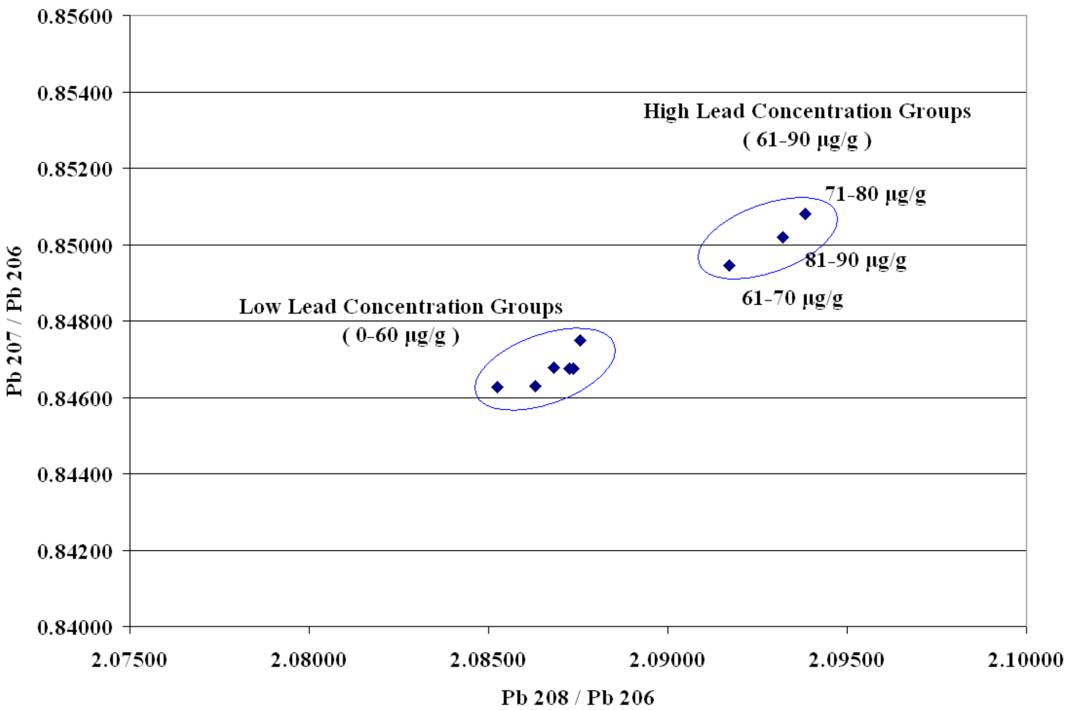

Figure 3. Average lead isotopic plot ($^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$) for each group in 10 µg/g increments in lead concentration

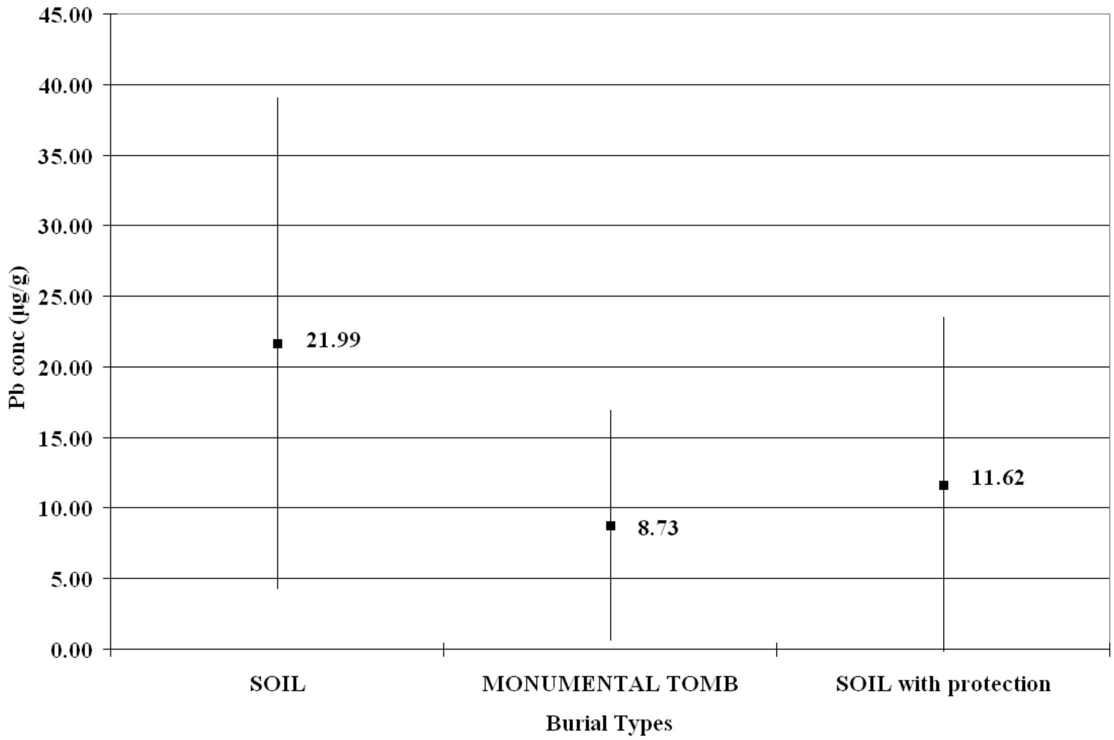

Figure 4. **Lead Concentrations in different burial arrangements**

Each square is average concentration, the length of each bar represents ± standard deviation.

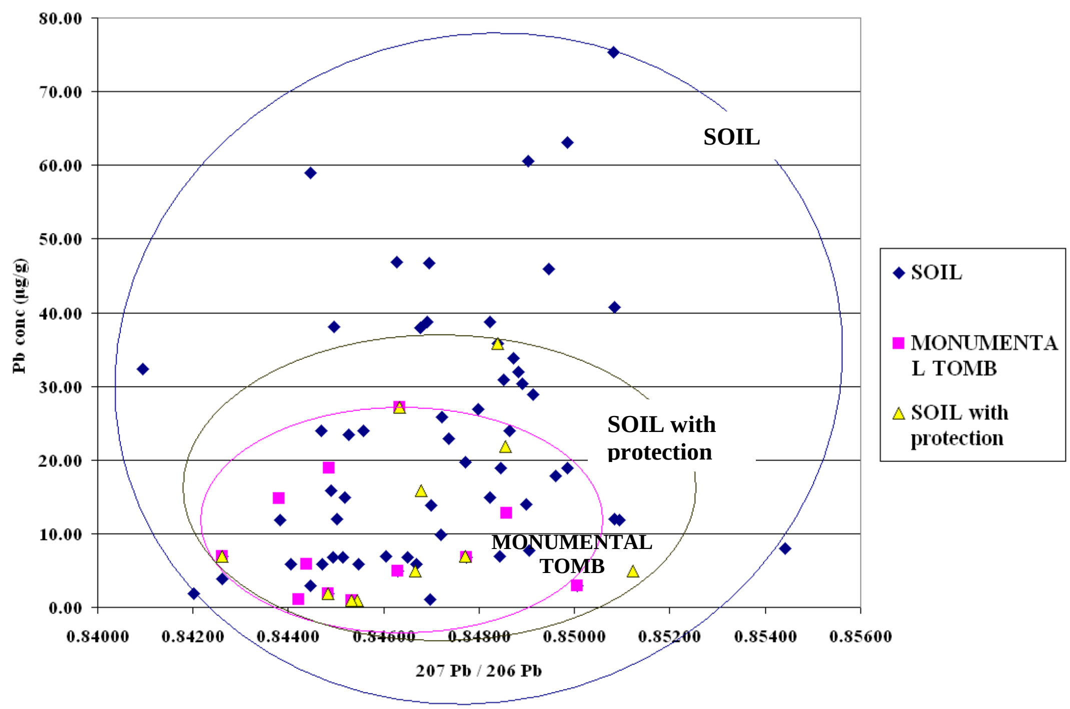

Figure 5. **Lead concentrations versus $^{207}Pb/^{206}Pb$ ratios for different burial types**

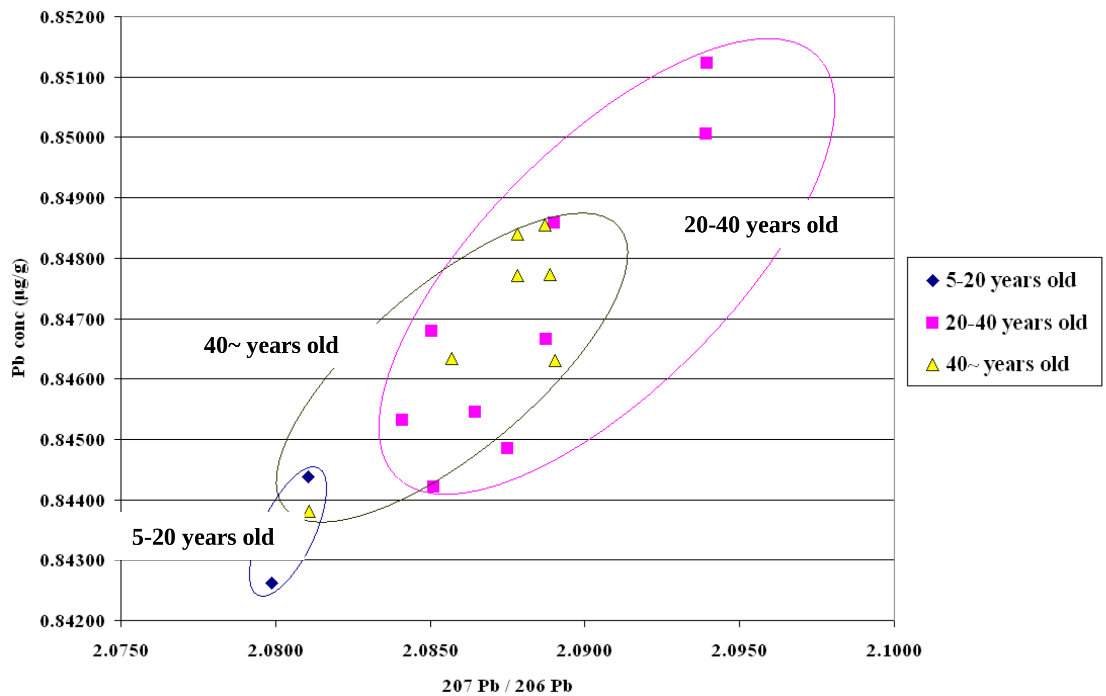

Figure 6. **$^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ for age groups of samples from protected monumental tombs.**

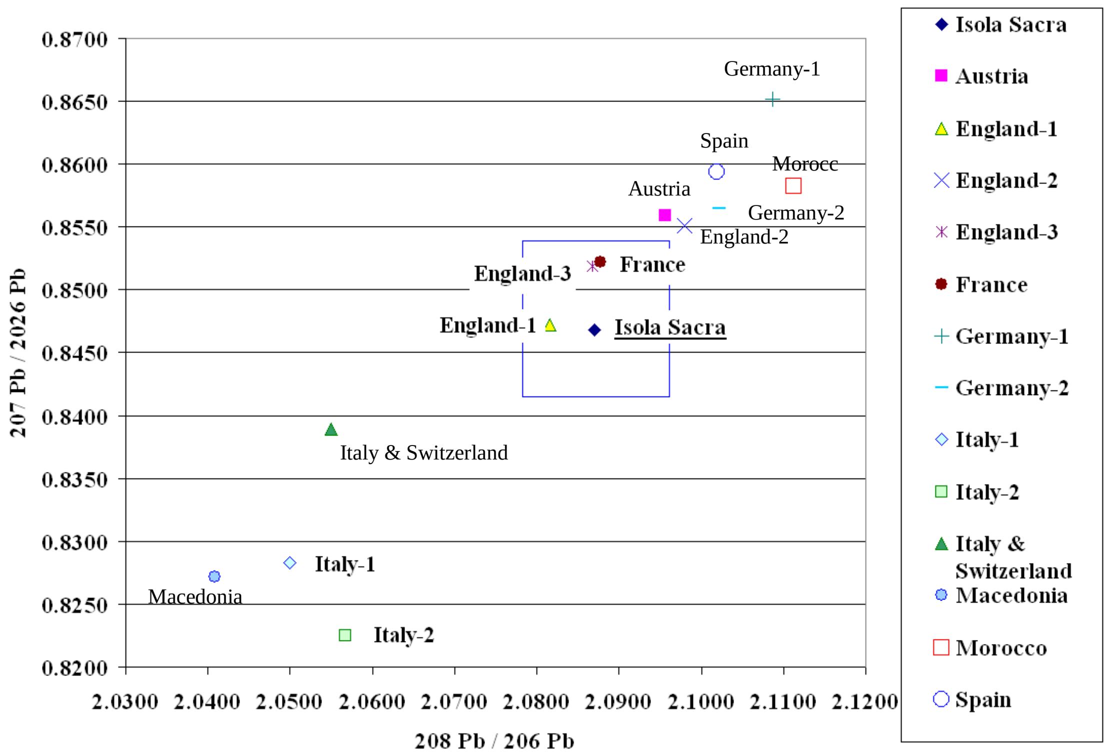

Figure 7. Isotopic Compositions in lead from principal ancient mining regions of Europe and Middle East in relation to the isotopic composition of bone lead from Isola Sacra. Sources of the data plotted are Austria (Doe, 1970); Bulgaria (Amov et al., 1981); England-1 (Haggerty et al., 1996a); England-2 (Haggerty et al., 1996b); England-3 (Bacon et al., 1995); France (Guen et al., 1992); Germany-1 (Doe, 1970); Germany-2 (Doe, 1970); Greece (Gale and Stos-Gale, 1982); Iraq (Al-Bassam et al., 1982); Italy-1 (Pettke and Frei, 1996); Italy-2 (Doe, 1970); Italy/Switzerland (Peretti and Koppel, 1986); Macedonia (Mudrinic and Serafimovski, 1992); Morocco (Doe, 1970); Norway (Anderson and Grorud, 1998); Spain (Pomies et al., 1998); Sweden (Sundblad et al., 1997).