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The Geochemistry of Intrusive Sediment Sampled from the 1st Century CE Inscribed Ossuaries of James and the Talpiot Tomb, Jerusalem

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Abstract

In 2002 an ossuary of unknown provenance was revealed to the public during a press conference; it is inscribed "*James son of Joseph brother of Jesus*". Because its inscription seems to refer to a member of the Jesus of Nazareth's family, it is natural to wonder what relationship this ossuary could have to the Talpiot tomb. Discovered in 1980 during construction operations in SE Jerusalem, the tomb contained several ossuaries inscribed with names from the Jesus family. In pursuit of physical evidence regarding such a relationship, we investigated the geochemistry of the James ossuary's sediment which accumulated through millennia in its interior. For comparison, we similarly investigated samples of material from ossuaries taken from the Talpiot tomb, and also from a wide sample of ossuaries from other tombs in the Jerusalem area. Our purpose was to answer, if possible, two questions. First, is the chemistry of the inorganic materials (soils) which were flushed into the Talpiot tomb and ossuaries therein distinct from other ossuaries removed from tombs in the Jerusalem area? Second, presuming such a distinction exists, does the geochemistry of the materials from the James ossuary resemble either grouping? While we recognize the controversies surrounding both the origin and inscription of the James ossuary and the interpretation of the Talpiot tomb inscriptions, this geochemical evidence is worth investigation and discussion on its own merits. Employing chemical (ICP, SEM and Pb isotope) analyses we have found, based on chemical data alone, that the ossuary of James is far more similar to ossuaries removed from the Talpiot tomb than it is to any other group of ossuaries we sampled.

1. Introduction

Ancient artifacts of unknown provenance are legion, they can be found in museums, private collections and in artifact markets. If not derived from a recorded excavation identifying their provenance can often be problematic. An ossuary inscribed with "*James son of Joseph brother of Jesus*" (Figure 1) hereafter referred to as the James ossuary, is just such an artifact. It was revealed to the public at a press conference in 2002. The inscribed ossuary, owned by an antiquities collector, was (ostensibly) purchased in the 1970s from a well known dealer in archaeological artifacts in Jerusalem's Old City. The inscription was authenticated by paleographers Professors Andre Lemaire of the Sorbonne, Paris and Ada Yardeni of the Hebrew University, Jerusalem. Soon after the ossuary's disclosure and while on display from November, 2002 to January 2003 at the Royal Ontario Museum in Toronto, a number of researchers (Ayalon et al., 2004; Silberman & Goren, 2003) announced that the inscription is a forgery. The accusation was later narrowed down to the second "brother of Jesus" portion of the inscription leaving the first "*James son of Joseph*" segment potentially authentic. After a seven year trial and over a hundred testimonies the case was thrown out of court for insufficient evidence to support the claim of a forged inscription and the ossuary was soon returned to its owner.

The ossuaries are inscribed:
Mary
Jesus son of Joseph
Judah son of Jesus
Jose
Mariamene Mara
Matthew

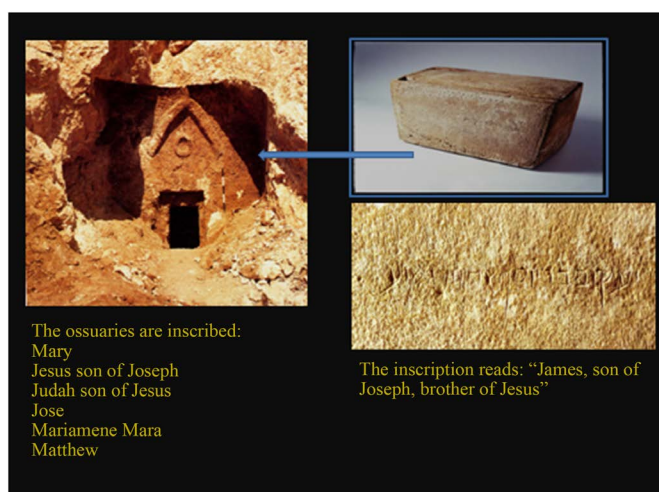The inscription reads: "James, son of Joseph, brother of Jesus"

Figure 1. The vestibule and entrance gate leading into the Talpiot tomb after its discovery by construction workers. The blocking stone was missing and the tomb was flooded by over 1/2 m depth of soil. Beneath are names (in English) inscribed on 6 of the 10 ossuaries. The unprovenanced inscribed ossuary of James, and its inscription, are on the right.

The Talpiot tomb was rapidly excavated soon after discovery by the Israel Antiquities Authority (IAA) and "apparently" ten ossuaries were deposited in the IAA collection in the Rockefeller Museum, Jerusalem. The names on the six inscribed ossuaries, five in Aramaic one in Greek, are, in English: Mary, Jesus son of Joseph, Judah son of Jesus, Jose (a brother of Jesus), Mariamene Mara (arguably Maria Magdalena) and Matthew. The first published data on the ossuaries was by Rahmani (Rahmani, 1994) and Kloner (Kloner, 1996), the inscribed names were viewed by the excavators (Kloner & Gibson, 2013) as typical for Roman period Palestine, consequently no attention was paid to the possible significance of the cluster of these names within what is, without any doubt, a 1st century CE tomb located about half way between Jerusalem and Bethlehem.

A Discovery Channel film "The Lost Tomb of Jesus" (Jacobovici, 2007) first suggested a link between the James ossuary and the group of inscribed ossuaries excavated from the Talpiot tomb. Although unprovenanced, the film maker reasoned that the ossuary, inscribed with the name of the oldest brother of Jesus and having made its appearance in a Jerusalem artifact dealer's shop, is the missing 10th ossuary excavated from the Talpiot tomb. The latter disappeared from the IAA collection at some unknown date and under rather mysterious circumstances (Kloner & Gibson, 2013: p. 45). Since the inscription alone does not provide unequivocal evidence of an ossuary's provenance we have sought another means to test this remarkable claim. For this purpose we embarked on a geochemical program of sampling and chemical analyses of soils flushed into the James and Talpiot tomb ossuaries, in addition we sampled a group of random ossuaries from tombs throughout Jerusalem (Figure 2a, Table 1). We reasoned that the Talpiot tomb ossuaries would produce a chemically identifiable population because a landslide, linked to a major earthquake that struck Jerusalem in 363 CE, dislodged the stone blocking the entrance into the tomb allowing soil and mud to flood the tomb. The excavators reported that when found the ossuaries were covered to a depth of over 0.5 m of soil (Kloner & Gibson, 2013). The absence of stratification in the sediment flooding the tomb and position of the ossuaries in their niches with lids on indicate that flooding occurred in a single short-lived event (Shimron & Shirav, 2015). Unlike the neighboring Patio and other tombs (Tabor & Jacobovici, 2012; Table 1) which missed the soil onslaught, the Talpiot tomb, like Pompeii covered with volcanic ash, became almost instantaneously sealed from most additional geological and geochemical processes. The latter affect most tombs by the addition of moisture carrying organic materials, soil, windblown dust and anthropogenic contaminants. Consequently the Talpiot tomb ossuaries were sent on an evolutionary path which differed from ossuaries in other tombs.

A review of the appearance, intrigues and eventually disappearance from most public discourse of the James ossuary can be seen in an article titled "CASHBOX" by journalist Jonathon Gatehouse in MACLEAN'S magazine (dated March 28, 2005). Tabor and Jacobovici (Tabor & Jacobovici, 2012) with considerably more tact and scholarly detail deal with the many challenging and indeed potentially

monumental issues regarding the discovery and significance of both the Talpiot and Patio tombs and inscriptions on the ossuaries uncovered therein. We refer the interested readers to articles in the James H. Charlesworth volume titled The Tomb of Jesus and His Family? (Charlesworth, 2013). Here we in particular recommend articles by: 1) J. H. Charlesworth (Introduction: Jerusalem's Tombs during the Time of Jesus, pp. 1-26); 2) C. Pellegrino (The Potential Role of Patina History in Discerning the Removal of Specific Artifacts, pp. 233-243); 3) A. Rosenfeld et al. (On the Authenticity of the James Ossuary and Its Possible Link to the Jesus Family Tomb, pp. 334-352) and 4) M. Elliott and K. Kilty (Who is in the Talpiot Tomb? A Statistical Approach, pp. 355-374). With the exception of the semi-quantitative (SEM) analyses of patina collected from tombs by Pellegrino and Rosenfeld (above) no scientific work has been carried out, before or since the present effort, on the ossuary of James and those removed from the Talpiot tomb. The tomb entrace has for decades been sealed by concrete.
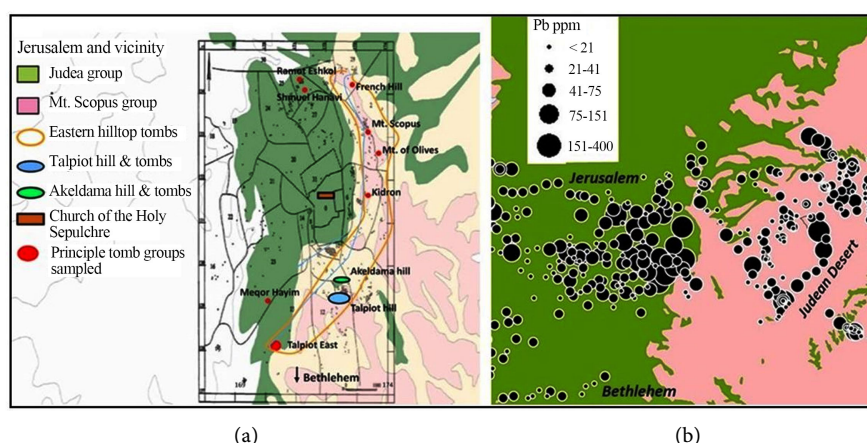

(a)　　　　　　　　　　　　(b)

Figure 2. **(a)** Overview of Jerusalem geology, major sites and tombs sampled. In West Jerusalem the Cretaceous Judea Gp. rocks consist mostly of limestone with lesser amounts of dolomite. In East Jerusalem the overlying Senonian Mt. Scopus Gp. is constructed of chalk with intercallations of flint with rare marl and phosphorite in the upper segment. **(b)** Urban Pb-pollution map. High concentrations of Pb are based on a GSI regional soil sampling program, in addition to Cr and Ni the anomalous area also contains high concentrations of other base and precious metals.

Table 1. List of ossuaries sampled, Israel Antiquities Authority (IAA) ossuary number, materials sampled, name of tomb (where available), Jerusalem city quarter or site.

Specimen (annal.) no.	IAA ossuary no.	Material sampled	Tomb-ossuary inscription	Location Jer. Quarter
Talpiot tomb ossuaries	*inscribed ossuary		Talpiot tomb	Armon Hanatziv
AS 2c	80 - 503*	soil fill	Jesus son of Joseph	"
AS 3c	80 - 504*	soil fill	Jose	"
AS 4c	80 - 502*	soil fill	Matthew	"
AS 5c	80 - 500*	soil fill	Mariamene Mara	"
AS 8c	80 - 508	soil fill		"

Continued

AS 20c	80 - 501*	soil fill	Judah son of Jesus	"
AS 21c	80 - 505*	soil fill	Mary	"
AS 51	James ossuary	soil fill	James son of Joseph brother of Jesus (not provenanced)	

Random ossuaries

AS 31A	Ossuary 6*	soil fill	Caiaphas tomb	Armon Hanatziv
AS 45	Ossuary 1*	soil fill	"	"
AS 47	Ossuary 7	soil fill	"	"
AS 48	Ossuary 7	int. floor crust	"	"
AS 6c	80 - 512	soil fill		"
AS 11c	69 - 125	int. floor crust		"
AS 13b	69 - 691	dust veneer		Meqor Hayim
AS 18c	68 - 688	int. floor crust		Ramat Eshkol
AS 22a		tomb soil	Shroud tomb	Akeldama hill
AS 22c		hill-slope soil		Akeldama hill
AS 23a		hill-slope soil		Talpiot hill
AS 24a		Composite (int.) sample	Shroud tomb	Akeldama hill
AS 24b		Composite (int.) sample	Shroud tomb	Akeldama hill
AS 25c		soil fill	Patio tomb	Armon Hanatziv
AS 26c		ossuary int. bottom crust	Shroud tomb	Akeldama hill
AS 1a		tomb interior soil	Shroud tomb	Akeldama hill
AS 1b		"	Shroud tomb	Akeldama hill
AS 1c		tomb exterior soil	Shroud tomb	Akeldama hill

Eastern hilltop tombs—EHT's

	S2576	soil fill		Mt. of Olives
	S2577	soil fill		Mt. of Olives
	S876	soil fill		Kidron valley
	69 - 153	soil fill		Mt. of Offence
	69 - 195	soil fill		Mount Scopus
	69 - 686	soil fill		French Hill
	71 - 429	soil fill		Mount Scopus
	74 - 1502	soil fill		Mount Scopus
	75 - 689	soil fill		Mount Scopus
	80 - 515	soil fill		East Talpiot
	80 - 522	soil fill		East Talpiot
Pt 1		tomb soil	Patio tomb	Armon Hanatziv
L9/2/15		airborne dust-loess		West Jerusalem

2. Materials and Methods

Table 1 lists the location of tombs and materials sampled and analyzed for the purpose of this study. These include samples of sediment (refered to as soil fill) sampled from ossuaries from the Talpiot tomb, from Random tombs (most from west Jerusalem) and ossuaries removed from tombs excavated into the hills bordering the eastern part of the city (the Eastern hilltop tombs). In addition, for comparison purposes, samples of soil were collected where feasible from the interiors of some tombs in addition from Talpiot and Akeldama hills (details below).

Burial tombs are cave-like features and the ossuaries within potentially act as small caves. Both provide access to water carrying soil and atmospheric pollution consequently, through millennia they are subject to continually varying geological and geochemical change. However ossuaries, such as those recovered from the Talpiot tomb for example, which lay buried beneath a thick layer of soil for ca. 1600 years of their history, will in major part, be sealed from such processes and instead follow a geochemical evolution related to their encapsulating soil. In our attempt at identifying and quantifying a chemical signature that can possibly be linked with the Talpiot, the James and other-random ossuaries we have sampled and studied the chemistry of the sediment flushed into the interior of the nine remaining Talpiot tomb ossuaries and, after its release from the Israeli courts, we sampled the remains of sediment which infiltrated the inscribed ossuary of James. For comparison purposes, ossuaries from some 25 additional tombs throughout Jerusalem were sampled and studied in an identical manner. We refer to the latter two groups of ossuaries as the Random and Eastern hilltop tombs ossuaries (EHT's, Table 1).

Equipped with this chemical data we focus on the following tasks: 1) determining the major and trace element (including Pb-isotopic) chemical composition of materials which invaded the Talpiot tomb ossuaries during almost two millennia of burial; 2) comparing and evaluating these data with chemical data obtained from the Random and EHT ossuaries removed from tombs throughout Jerusalem; and 3) documenting any chemical characteristics (major and chosen trace elements) distinguishing one group from another.

Due to technical issues, sampling of ossuaries and chemical analyses was carried out in three stages between March 2009 and December 2014. Sampling of ossuaries from the EHT group (including tombs from French hill, Mt. of Olives, Mt. Scopus and Talpiot hill in south Jerusalem (also referred to as Hill of Evil Counsel or Armon Hanatziv, Table 1, Figure 2a) was carried out last, it was done especially to compare chemical data from the latter with the data from the Talpiot tomb and Random ossuaries. The above data is finally compared with chemical data from soil sampled from the James ossuary (Figure 3, Figure 4). Samples of representative soils were collected from Talpiot hill (Mt. Scopus group-Pale Rendzina soil, some 100 meters distal from the Talpiot tomb) and from near the Akeldama monastery in East Jerusalem (Akeldama hill, Figure 2a) where numerous burial
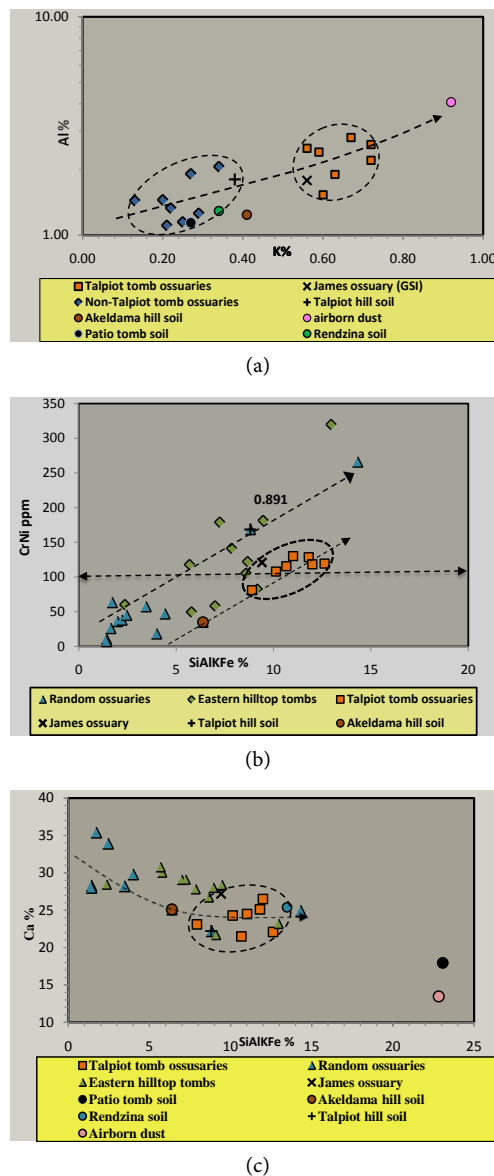
(a)

(b)

(c)

Figure 3. (a) Scatterplot of Al vs. K. The James ossuary, although peripheral (due to its higher Ca content) falls into the well defined TT ossuaries cluster. Soils of the non-Talpiot tomb ossuaries including the Talpiot hill soil and average for Rendzina soils all fit well within a different (lower Al and K) compositional cluster. The chemistry of the airborn dust is entirely outside both these concentrations thus implying foreign sources. **(b)** Scatterplot of CrNi vs. SiAlKFe. A strong positive correlation (R = 0.891) between the two groups of collective variables CrNi and SiAlKFe is seen. The Talpiot hill Pale Rendzina soil is in major part derived directly from, and thus reflects, the underlying chalk-flint bedrock, it contains more Cr and Ni then most other ossuaries we examined. The chemistry of the James ossuary fits well into the TT ossuaries cluster. **(c)** Scatterplot Ca vs. SiAlKFe (combined). The TT ossuaries cluster is well defined on this scatterplot although a few peripherial values from other tombs are also included. There is a very good negative correlation between Ca and the aluminosillicates. The James ossuary is peripheral but within the TT cluster, we can attribute this to the high concentration of bone Ca (see P values in **Figure 4c**) in the latter. With respect to the aluminosilicates the James and TT ossuaries, the Talpiot hill soil and average for Rendzina soil all fall into the same compositional cluster.

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tombs (e.g. the Shroud tomb, Table 1) were excavated into Judea Group limestone. The latter are covered mostly by Brown Rendzina and Terra Rossa soils (Dan et al., 1971; Arkin et al., 1976; Singer, 2007). Talpiot hill was until the 1970's mostly isolated from vehicular traffic and thus petrol Pb contamination, Akeldama hill, on the other hand, was for decades near abundant vehicular traffic and therefore subject to urban contamination.
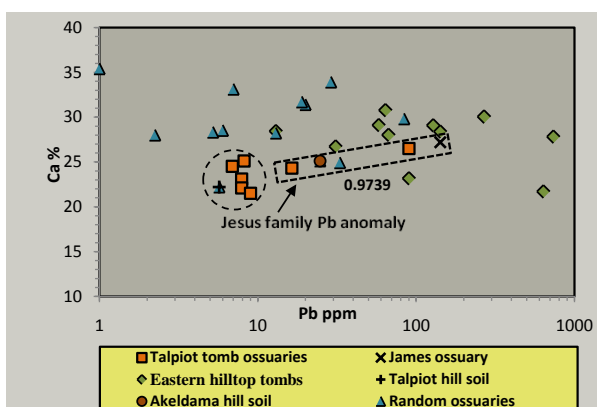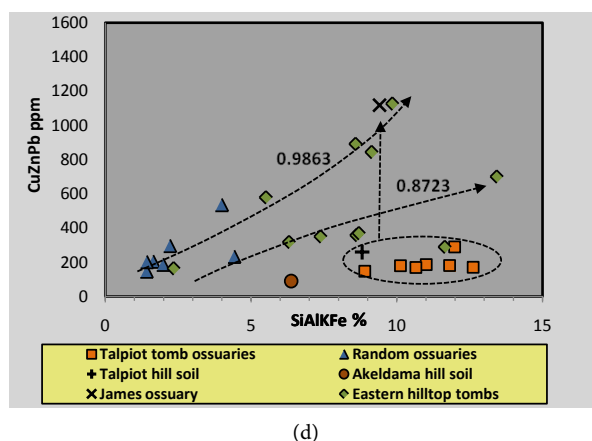

(a)
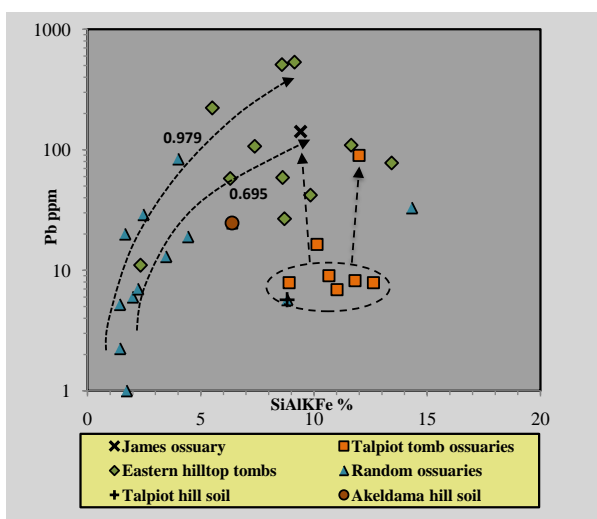
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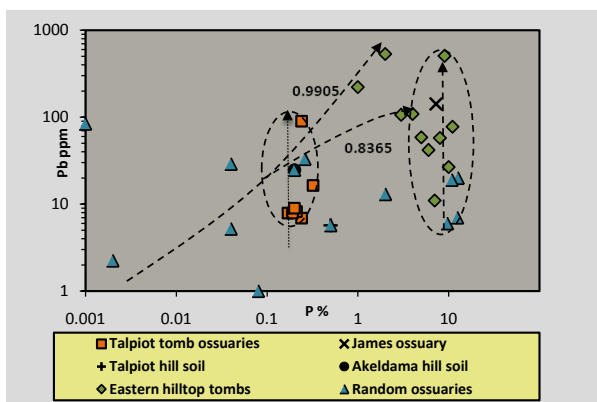
(c)

(d)

Figure 4. (a) Scatterplot of Ca vs. Pb. The soils inside most of the Talpiot tomb ossuaries (including the Talpiot hill soil), are well characterized by their lower Ca and Pb concentrations from most ossuaries of other tombs. An exceptions is the cluster containing the soil values from the Jesus, Mary and James ossuaries (Pb =16 - 142 ppm) and also including the polluted Akeldama hill soil. The positive correlation between Ca and Pb for the cluster values is defined by Pearson's correlation coefficient (R = 0.9739), such a correlation implies the influence of bone apatite (see Figure 4c). (b) Scatterplot of Pb vs. SiAlKFe. The plot exhibits a strong to moderate positive correlation between Pb with SiAlKFe in the Random and EHT ossuaries (two best fit curves R = 0.979 and R = 0.695). Such is not the case for the TT ossuaries. The Pb values for the James, Mary and Jesus ossuaries are probably an exception as they seem to record a different, more complicated story (Figure 4a, Figure 5 and Figure 6). A concentration of 1 ppm Pb in bone is viewed by the WHO as a level of concern, 10 ppm and above as severe poisoning, and in normal soils a Pb concentration above 20 ppm (horizontal arrow above) is viewed as anomalous. It is noteworthy that virtually all soils sampled from the EHT ossuaries carry anomalous concentrations of lead. (c) Scatterplot of Pb vs. P. Two best fit trendlines (the lower includes the James ossuary) define two possible positive correlation trends linking Pb with P. Two clusters, one for the TT (including Akeldama hill) soils and the other in the high P range (5% - 12% P) for some Random and most EHT ossuaries, do not show any correlation between Pb and P (bone). The latter values can be attributed to urban polution (Figure 2b). (d) Scatterplot for the elements groups CuPbZn vs. SiAlKFe. Two best fit trendlines connecting most Random and EHT values reveal very good positive correlation (R = 0.9863 and R = 0.8723) between the contaminating metals and the aluminosilicates where the metals are concentrated. The Talpiot tomb ossuaries group are an exception as they do not record such a correlation between the polluting metals and soil chemistry (Figure 4b). We emphasise that *without its unique metal contaminants* (1119 *ppm combined metals) the James ossuary would fit well within the TT ossuaries group.*

For GSI and Bactochem data major element, and also Sr, Ba and Zr concentrations, were determined by ICP-OES (Perkin Elmer, OPTIMA 3300) after lithium metaborate (LiBO$_2$) fusion using Sc as internal standard. Each analysis run included repeated determinations of four of the international standards NBS-88A, JB-1, SO-3, SCO-1, BHVO-1, and BCR-32. Trace element, including rare earth elements (REE) were determined by ICP-MS (Perkin Elmer, NextION 300D) after sintering with sodium peroxide (Na$_2$O$_2$) and dissolution by acid (HNO$_3$) using Rb and Re as internal standards. Each analysis run included repeated determinations of international standards NBS-88A, JB-1, SO-3 and SCO-1.

The isotopic compositions of Pb were measured using a Nu Plasma MC-ICP-MS instrument. The isotopic mass discriminations of the MC-ICP-MS were corrected by the usage of [205/203]TI ratio and repeated measurements of the SRM-98 standard. The long-term precision of isotopic ratio determinations (2α, relative standard error) was ~0.02‰ for both 206 Pb/204Pb and 207 Pb/204Pb rations, and 0.05‰ for the 208 Pb/204Pb.

For the EHT (Bergen) group of samples between 1 and 4 g of soil was powdered using a ring mill. For loss on ignition (LOI) ca. 3 grams of the powered samples were accurately weighed, transfered into crucible and heated to 1000°C for two hours in an oven, and then weighed again. During this procedure all volatile components present in the samples (H_2O and CO_2) were removed, and the loss-on-ignition (LOI) was thus calculated. For the major element oxides and trace elements 200 milligram of powder of each of the heated samples was subsequently dissolved in concentrated hydrofluoric acid (HF) in a Teflon beaker. All the major oxides (except SiO_2) and Li were analyzed on an optical ICP instrument (Thermo Scientific ICAP 7600). When dissolving the samples in hydrofluoric acid silicon is lost in the process, hence for determining the SiO_2 concentration glass beads were prepared for XRF-analyses. Each sample (0.96 grams) was mixed with 6.72 grams of lithium tetraborate ($Li_2 B_4O_7$) as a flux and melted. Glass beads were thus made using a fusion furnace (Claisse, model Fluxy) that was running at around 1000 degrees Celsius for 30 minutes, while steering the samples automatically. The samples were then XRF-analyzed for SiO_2 on a S4 PIONER X-ray spectrometer. Pb-isotopes, the REEs and all the other trace elements (except Li) were analyzed on an ICP-MS instrument (Thermo Scientific Element XR). The international standard BCR-2 was used to calibrate the results, and a solution of Scandium was used as an internal standard. The chemical processing was carried out in a clean-room environment with reagents purified in two-bottle Teflon stills. Samples were dissolved in a mixture of HF and HNO 3. Strontium was separated from the other elements using a Sr-specific ion exchange resin.

SEM examinations were carried out at the Hebrew University Nanolaboratory (The XPS Laboratory Unit for Nanocharacterization, The Harvey M. Krueger Center for Nanoscience and Nanotechnology) in Jerusalem by Dr. Vitaly Gutkin (supervisor of the unit) and AES. Technological analysis was conducted using both a stereomicroscope (magnification: 10 - 40 x) and a scanning electron microscope. The scanning electron microscopy images were obtained using an FEI Quanta 200 ESEM in low-vacuum mode without any preliminary treatment and with a chamber pressure of 0.38 Torr and acceleration voltages of 15 - 20 kV.

Sampling of sediment flushed into the Talpiot and Random tombs ossuaries was carried out by technician Oded Reviv of the IAA and sampling of the James and EHT ossuaries by AES, done in an identical manner. Material was collected using a stainess steel spatula from the little sediment that still remained inside most ossuaries, this was not always possible as many were entirely cleaned out

and emptied of all materials in the interior. Occasionally, the little soil remaining on the ossuary floor formed a 1 - 2 cm crust of sediment rubble mixed with degraded bone cemented by carbonate flowstone.

3. Analyses and Findings

We have studied our chemical analyses (Table 2) and present the data in four ways. First we show a series of chemical element scatterplots (Figures 3a-c) intended to convey the chemical evolution of the major and some minor (Cr, Ni) elements in the three (the Random, the EHT's and Talpiot tomb) groups of ossuaries versus the James ossuary. Second, we focus on lead (Pb, Figures 4a-c) whereby we try to understand its relationship to the chemistry of the host rock followed by examination of anomalous Pb values in the Jesus, Mary and the James ossuaries and try to understand their significance, if such exists. We then focus on the heavy metals Cu, Pb and Zn (Figure 4d, Figure 5a, Figure 5b) and finaly discuss the significance of our Pb isotope data (Figure 6). Next we apply a *likelihood analysis* to some chosen major elements (Figure 7) and finaly perform a factor analysis where, besides the major elements, we pay attention also to some of the trace and rare earth elements (REE's, Figure 8). For technical reasons, we could not obtain chemical data using all methods for every sample for each ossuary.

Table 2. Chemical data from all sources (five Talpiot tomb inscriptions are in Aramaic, the Mariamene Mara in Greek).

BACTOCHEM

Talpiot tomb ossuaries			Si	Al	Fe	K	Na	Ca	Mg	Ti	P	Ba	Co	Cr	Cu	Mn	Ni	Pb	Sr	Zn
Sample	Oss. no.	Inscription-location	%	%	%	%	%	%	%	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
AS 2c	80 - 503	Yeshua bar Yehosef	5.4	2.4	1.74	0.59	0.2	24.3	0.72	1005	0.32	130	7.7	74.9	34.9	206	33	16.4	340	129
AS 3c	80 - 504	Yoseh	4.6	1.53	1.2	0.6	0.21	23.1	0.49	1380	0.17	143	7.4	56	26	223	25	7.9	1180	114
AS 4c	80 - 502	Matyah (Matytyahu)	6.1	2.5	1.85	0.56	0.1	24.5	0.76	661	0.24	115	7.4	87.7	36.5	228	42.5	6.9	359	143
AS 5c	80 - 500	Mariamene Mara	6.34	2.8	2	0.67	0.16	25.1	0.8	956	0.21	143	8.5	88	30	244	40.6	8.2	332	143
AS 8c	80 - 508	no inscription	7.5	2.6	1.8	0.72	0.183	22.1	0.78	946	0.19	172	8.4	79.5	28	241	40	7.9	325	135
AS 20c	80 - 501	Yehuda bar Yeshua	6	2.2	1.74	0.72	0.19	21.5	0.58	858	0.2	151	8.5	78.6	31.4	222	37	9	305	130
AS 21c	80 - 505	Marya	8.24	1.9	1.22	0.63	0.16	26.5	0.4	668	0.24	139	8.2	78	30.7	207	40.5	90	425	170
Random ossuaries																				
AS 6c	80 - 512	Armon Hanatsiv	1	0.2	0.143	0.079	0.69	28.3	0.71	104	0.04	128	1.2	17.8	20.7	26	10.9	5.2	923	121
AS 11c	69 - 125	prob. Jerusalem	2.86	0.55	0.36	0.23	0.2	29.8	0.13	226	0.001	209	2.89	37	31.6	53.6	18.2	84	423	420
AS 18c	68 - 688	Ramat Eshkol	0.98	0.21	0.13	0.11	0.413	28	0.08	76.6	0.002	33	1.1	28	24	16.6	7.21	2.24	308	176
GSI																				
AS 51		James son of Joseph brother of Jesus	5.93	1.78	1.14	0.56	0.49	27.2	0.5	1400	7.24	350	11	100	1119	300	21	142	534	425

Continued

Random ossuaries			Si	Al	Fe	K	Na	Ca	Mg	Ti	P	Ba	Co	Cr	Cu	Mn	Ni	Pb	Sr	Zn	LOI	Total
			%	%	%	%	%	%	%	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	%
AS 31A	Oss. 6	Caiaphas tomb	1.3	0,2	0.15	nd	nd	31.4	0.12	200	12.6	70	1	14	28	25	26	20	386	157		
AS 45	Oss. 1	"	1.58	0.12	0.29	nd	nd	28.5	0.12	200	9.6	160	2	43	1	25	36	6	557	144		
AS 47	Oss. 7	"	3.1	0.84	0.49	nd	nd	31.7	0.18	700	10.8	250	3	61	80	63	47	19	554	134		
AS 48	Oss. 7	"	1.54	0.47	0.21	nd	nd	33.1	0.12	300	12.4	330	2	48	107	24	38	7	629	183		
AS 25c		Patio tomb	8.44	3.36	2.16	0.36	<0.1	24.9	0.6	2600	0.26	215	14	155	74	300	111	33	378	310		
AS 26c		Shroud tomb	1.59	0.49	0.29	0.09	0.21	33.9	0.5	400	0.04	102	2.8	44	39	100	<1	29	410	182		
AS 24a		"	2	0.67	0.46	0.34	0.12	28.2	0.3	325	2.00	69.6	4.3	35	32	84	22.4	13	391	100		
AS 24b		"	1.2	0.21	0.13	0.184	0.067	35.4	0.14	71.8	0.08	20.7	0.7	44.4	11	15	19	1	747	49		
AS 22c		Akeldama hill soil	3.95	1.24	0.78	0.41	0.07	25.1	0.26	309	0.2	58	3.6	23	20	141	12	24.7	132	45.7		
AS 23a		Talpiot hill soil	5.5	1.8	1.13	0.38	0.08	22.2	0.43	354	0.5	92	4.4	118	37.4	125	50.6	5.7	309	217		

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EHT ossuaries	Location	Si	Al	Fe	K	Na	Ca	Mg	Ti	P	Ba	Co	Cr	Cu	Mn	Ni	Pb	Sr	Zn	LOI %	Total %
S 2576	Mt. of Olives	4.08	0.83	0.69	0.19	1.72	30.04	0.60	1000.00	8.59	135	5	33.9	41.3	123.4	15.7	222.3	291.7	316.5	21.62	98.39
S 2577	Mt. of Olives	5.70	1.11	0.83	0.21	0.01	27.82	1.11	1100.00	0.64	236	10	97.1	73.9	140	44.2	533.3	580.4	237	37.82	96.02
S 876	Kidron Valley	4.76	1.15	0.84	0.25	0.08	29.08	0.54	1300.00	8.89	199	6	40.8	36.7	137.5	17.5	106.7	330.8	207.5	20.07	96.25
69 - 153	Mt. of Offence	6.16	1.91	1.13	0.27	0.01	28.39	0.52	1500.00	2.76	159	5	121.5	43.1	163.8	60	109.2	584.6	137.7	30.81	96.76
69 - 195	Mt. Scopus	6.93	0.90	0.60	0.16	0.08	28.02	0.18	900.00	11.15	66	4	70.2	55.3	49.1	35.1	58.8	337.7	244.7	13.60	96.53
69 - 686	French Hill	4.63	1.45	0.96	0.20	nd	29.11	0.49	1400.00	0.47	138	13	122.5	34.1	216.6	56.5	42	477.5	1051	37.80	94.93
71 - 429	Mt. Scopus	1.66	0.35	0.29	0.07	0.22	28.44	0.37	10000.00	12.54	99	2	46.6	26.3	32.2	13.6	11	478	127.1	18.42	92.75
74 - 1502	Mt. Scopus	3.21	1.44	0.91	0.13	0.09	30.77	0.19	1100.00	13.44	68	5	72	39.6	102.7	45.9	57.7	182	221.6	11.30	96.87
75 - 689	Mt. Scopus	6.58	1.26	0.98	0.29	0.03	21.70	0.71	1600.00	5.64	276	8	55.2	68.8	148	27.2	508.8	296.8	315.2	25.03	95.07
80 - 500	Talpiot tomb	8.74	2.48	1.89	0.37	0.01	20.53	0.63	2500.00	0.36	205	19	129	43.6	306.1	58	9.16	387.8	174.8		
80 - 503	Talpiot tomb	10.54	2.66	1.77	0.39	0.39	23.09	0.71	1400.00	0.5	199	18	106.9	32	296.2	48.9	8.4	401.5	137.4		
80 - 505	Talpiot tomb	7.63	1.74	1.37	0.31	0.11	22.61	0.45	2000.00	0.22	218	17	112.9	38.3	251.1	48.9	72.2	508.5	191.7		
80 - 515	East Talpiot	6.15	1.33	0.97	0.22	nd	26.73	0.52	2600.00	10.2	159	6	79.1	69.8	91.4	43.1	26.7	729.3	273.3	15.85	95.51
80 - 522	East Talpiot	9.13	2.06	1.43	0.34	0.10	23.17	0.72	2500.00	8.59	167	10	206.9	74.1	136.2	112.9	77.6	399.1	550	16.22	95.95
L 9/2/15	Airborn dust	17.70	4.07	2.94	0.92	0.50	13.48	2.15	4600.00	0.1	445	25	108	46	666	37	16	528	189	23.5	98.47
Pt 1	Patio tomb soil	20.82	1.14	0.78	0.27	0.02	17.95	0.24	1100.00	0.07	nd	nd	nd	nd	nd	nd	nd	nd	nd	22.32	96.4
Soil A	Rendzina on chalk	9.37	1.29	2.48	0.34	0.19	25.39	1.56	nd.	0.41	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Soil B	Rendzina on marl	18.80	5.94	8.41	1.05	0.63	10.60	1.89	nd.	0.83	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Soil C	Terra Rosa-Judea	29.30	9.00	6.08	1.25	0.23	1.23	1.33	0.85	0.05	0.04	31.00	187	32	nd	66	18	129	104	nd	nd

Elem	Wt %	At %
C K	5.48	19.00
O K	12.78	33.25
MgK	0.15	0.26
A l K	1.35	2.08
S i K	3.66	5.42
P K	5.19	6.98
C l K	1.32	1.55
K K	0.69	0.74
C a K	18.95	19.68
F e K	1.67	1.24
P b L	48.75	9.79
T o t a l	100.00	100.00

Elem	Wt %	At %
C K	3.57	19.29
O K	8.41	34.10
MgK	0.18	0.49
A l K	1.03	2.48
S i K	1.66	3.83
C a K	9.55	15.47
F e K	0.78	0.91
P b L	74.81	23.43
T o t a l	100.0	100.00
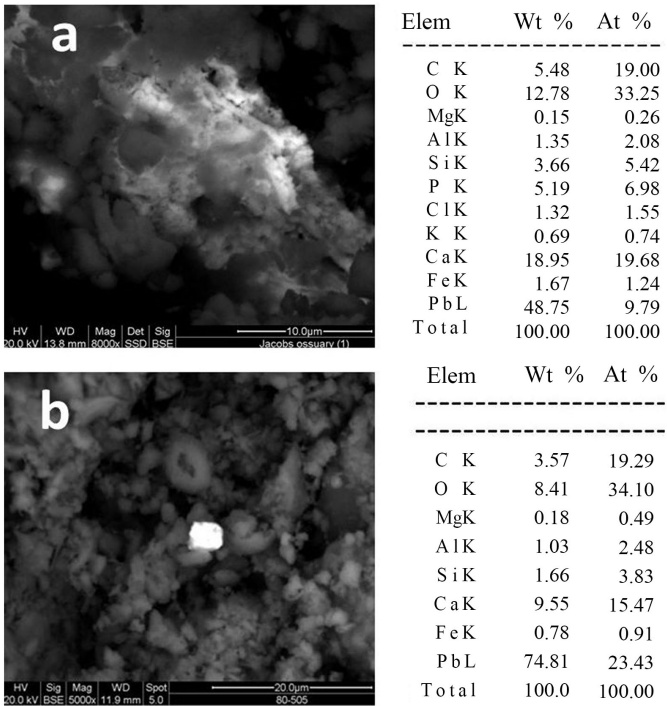
Figure 5. (a) Scanning Electron Microscope (SEM) photograph illustrating James ossuary soil fill contaminated by metallic (white). The lead appears to be assimilated and spread within bone tissue. Bone tissue is indicated by the high P and Ca content. **(b)** SEM photograph showing an isolated fragment of Pb in the soil fill from the Mary ossuary. The lead chip is an isolated, clearly late foreign intrusion, it is detached from the soil matrix. Note that in contrast to (a) there is no detectable P and little Ca in this chemical analysis.
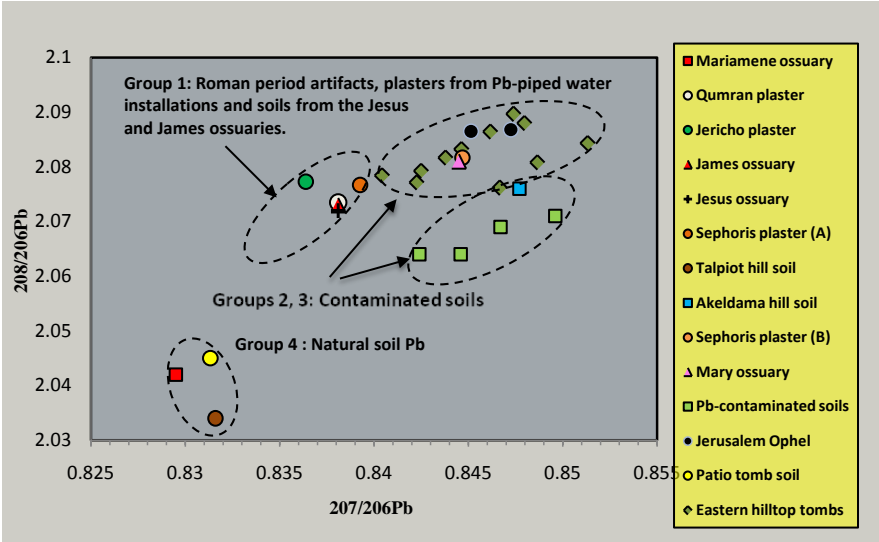

Figure 6. Plot of the isotopes $^{208/206}$Pb vs. $^{207/206}$Pb. Group 1 contains the isotope values for the James and Jesus ossuaries and plasters from Roman period water installations. Group 2 encloses values for soils from the EHT ossuaries, the Mary, one Sepphoris and two Ancient Jerusalem (Ophel) water installations. Group 3 contains values for contaminated soils and Group 4 values for soils from the Mariamene ossuary, Patio tomb and Talpiot hill.
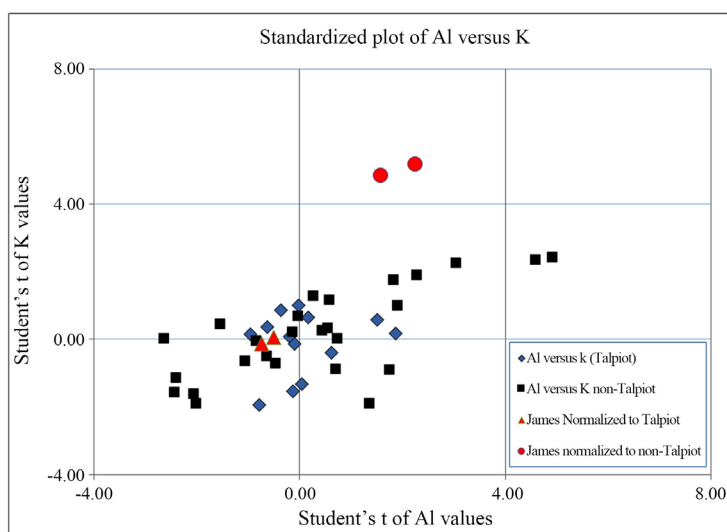
Figure 7. Studentized major element data from all labs. The various symbols represent chemical assays for K and Al from random tombs normalized by their mean and standard deviation; and assays for Talpiot tomb ossuaries normalized similarly. Thus, all plotted data are effectively Student's t deviates—they all plot about the origin and rarely beyond a value of 3.0. The larger symbols represent our two assays from the James ossuary normalized using parameters from these two groups in turn. Note that normalizing by Talpiot tomb mean and standard deviation plots near the center of the diagram, while normalizing by random ossuary mean and standard deviation produces unlikely outliers.
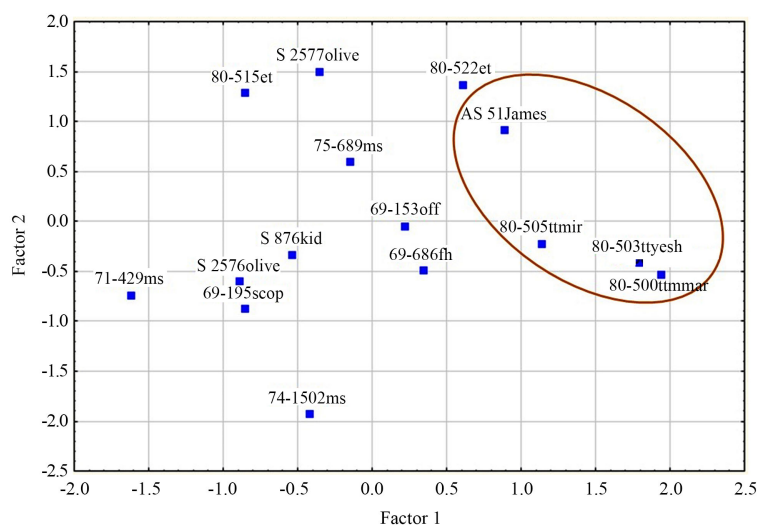
Figure 8. Factor analysis scatterplot. In spite of the wide scatter of points for the TT ossuaries the James ossuary (point AS 51 James) reveals its almost certain affiliation with the Talpiot tomb group. Ossuary 80 - 522 (point 80 - 522 et) was removed from an East Talpiot tomb, it is located about 400 south from the Talpiot tomb in what is an identical geological setting and thus soil of similar compositiom.

3.1. Scatterplots for Selected Major and Trace Element Concentrations

We use scatterplots to display the chemical relationship between two variables each variable representing a set of chemical data (Table 2). Scatterplots demonstrate

graphically the presence or absence of a relationship between the variables, correlation between chosen elements may be positive, negative, or null and their strength can be characterized by a best fit trendline and quantified (0 – 1.0) by Pearson's correlation coefficient. For variables we have used either single elements but for some plots we have combined the total concentrations of a number of related elements. For example, we have taken the liberty to combine Cr and Ni and also the heavy metals Cu, Pb and Zn as they collectively manifest important urban pollution characteristics within and around the city of Jerusalem (Figure 2b, Shirav et al., 1997). In a similar manner we occasionally use the concentration of the elements Si, Al, K and Fe collectively (refered to as aluminosilicates) since they best represent the clayey and more rarely the siliceous (flinty) soils of Jerusalem.

Jerusalem's geology encompasses the Upper Cretaceous (Cenomanian and Turonian) Judea Gp. limestones with minor dolomite and the Senonian Mt. Scopus Gp. comprised of chalk in the lower and flint with rarely phosphorite in the upper part. The Senonian rocks principally occupy the East Jerusalem hilltops cut along their west margins by the N-S trending Kidron valley (Figure 2a, Figure 2b). As they are frequently constructed of soft chalk most ancient burial tombs have been carved into these rocks. In West Jerusalem Brown Rendzina and Terra Rossa soils formed above the Judea Gp. limestones whereas covering the East Jerusalem hilltops are mainly Pale Rendzina soils covering the Mt. Scopus chalk and flint units. The former soils are enriched in Mg, Mn, Si and Co, whereas the latter Rendzina soils carry a chemical signature characterized by the elements Zn, Cd, Cr, Ni, U and V among others (Singer, 2007).

In Figure 3a we show the relation between the Al and K components in ossuaries' soils. The chemical distinction between the non-Talpiot and Talpiot tomb groups of ossuaries (the latter including the James) is unambiguous. Furthermore, a marked distinction of the TT group of soils (with the James) is shown in the plot for CrNi vs. SiAlKFe (Figure 3b). We can probably attribute most of the higher (above the 100 ppm line) concentration of Cr and Ni in most EHT, TT and James ossuaries, including the Talpiot hill soil, to the unique chemical milieu generated by weathering of the Senonian chalk-flint bedrock. Figure 3c illustrates the expected negative correlation between Ca (the carbonate fraction of soil) and the combined SiAlKFe (clay) fraction. We note that the James is peripheral, we can attribute this to Ca enrichment attributed to the high bone content of the James ossuary (Figures 4a-c).

In Figure 4a we show the relationship betwee Ca and Pb. Since the reservoir for natural Pb in soils are the aluminosilicates and Fe-oxides rather than carbonates (Teutsch et al., 2001 and Figure 4a, Figure 4b) it appears that some of the Pb enrichment can be attributed to other potential lead contributors. One such Pb source is implied by the bone content (note the high P and Ca concentrations in the James) but also anthropogenic contamination caused by urban pollution by petrol Pb, and also metal objects (Figure 5a, Figure 5b) from workshops and artifacts. Nonetheless, on the basis of published data pertaining to urban contamination of local soils (Teutsch et al., 2001; Erel et al., 1997) we can attribute

most of the high Pb concentrations in the EHT's to contamination by anthropogenic Pb contributed to local sediment from leaded petrol fuel. Although the Mary, James and marginally Jesus, ossuaries are enriched in Pb (Figure 4c), in contrast, most Talpiot tomb ossuaries, and the Talpiot hill soil, are depleted in the combined metals (Figure 4d). We also note that while there is no correlation between the concentration of Pb and P in some Random and most EHT ossuaries (Figure 4c vertical arrows) the distribution of data points for some of the Random, EHT and the James ossuaries reveals a moderate to strong positive correlation (R = 0.9905 and R = 0.8365) with P, implying therefore what may be a significant link of Pb with bone.

We studied this rationale further by examining the soil collected from the James ossuary in the Scanning Electron Microscope (SEM). In the photograph (Figure 5a) the lead is dispersed throughout bone tissue implying that assimilation of Pb within bone in the James ossuary can be viewed as an ancient phenomenon. In contrast, the Pb fragment (Figure 5b) is clearly an isolated, late-introduced contaminant. SEM examination of this and other samples revealed a broad range of such isolated fine chips of metalic Pb, Cu, Fe, PbSnZn (pewter) and Au. Possible sources for Pb contributions into the ossuaries, the James in particular, include: 1) organic lead absorbed by the system ingested as lead acetate with wine and/or 2) Pb introduced as a contaminant in the artifact dealer's shop in Jerusalem's Old City or 3) the home of the artifacts collector where the James resided for some years. Another source 4) may be ceremonial—that is chips detached from jewelry inserted into the ossuary of James, first Bishop of Jerusalem prior to his burial.

3.2. Pb Isotope Analyses

Since the isotopic composition of lead remains unchanged from the original ore into metal during refining, smelting and weathering processes, Pb isotopes are important tools in provenancing ancient materials and artifacts. We determined the Pb isotopes on some of the relevant materials available to us for sampling and study—soil fills from three inscribed Talpiot tomb ossuaries (the Jesus, Mariamene and Mary) and 11 samples from the EHT ossuaries. In addition we analyzed the two samples representing Jerusalem's main soils, the Talpiot hill Pale Rendzina and Akeldama hill Brown Rendzina or Terra Rosa soil. Soil was also collected by a robotic arm from the Patio tomb floor. The latter is located 60 m west of the Talpiot tomb and is an important archaeological site potentially linked to early Christianity (Tabor & Jacobovici, 2012). Because of their relevance we also utilized Pb isotopic values from previous studies, they include data on petrol Pb-contaminated Israeli soils (Teutsch et al., 2001; Erel et al., 1997) and Pb isotope data obtained from hydraulic plasters from installations in ancient Jerusalem, Judean Desert (Qumran), Jericho (Palace of the Kings) and the Sepphoris antiquities site in the Galilee (Shimron, 2003; Shimron, 2018).

A plot of the isotopes $^{208/206}$Pb vs. $^{207/206}$Pb (Table 3 and Figure 6) shows a

Table 3. Pb isotope data from all sources.

Bergen (EH tombs)				
Sample	Area-tomb	Material	$^{208}Pb/^{207}Pb$	$^{207}Pb/^{206}Pb$
S 2576	Mt. of Olives	ossuary soil	2.0880	0.8480
S 2577	Mt. of Olives	"	2.0897	0.8474
S 876	Wadi Kidron	"	2.0865	0.8462
69 - 153	Mt. of Offence	"	2.0784	0.8404
69 - 195	Mt. Scopus	"	2.0817	0.8438
69 - 686	French Hill	"	2.0808	0.8487
71 - 429	Mt. Scopus	"	2.0762	0.8467
74 - 1502	Mt. Scopus	"	2.0833	0.8446
75 - 689	Mt. Scopus	"	2.0793	0.8425
80 - 515	East Talpiot	"	2.0771	0.8423
80 - 522	East Talpiot	"	2.0843	0.8513
Pt 1	Patio tomb soil	"	2.0450	0.8313
GSI				
Sample	Area-tomb	Material	$^{208}Pb/^{207}Pb$	$^{207}Pb/^{206}Pb$
80 - 500	Talpiot tb.	ossuary soil	2.042	0.8295
80 - 503	Talpiot tb.	"	2.072	0.8381
80 - 505	Talpiot tb.	"	2.081	0.8445
AS 51	James oss.	"	2.073	0.8381
AS 1 - 17	Akeldama soil	hill soil	2.076	0.8477
AS 23	Talpiot hill soil	hill soil	2.034	0.8316
A14a	Jericho	plaster	2.0773	0.83639
Q20a	Qumran	"	2.0735	0.8381
A36a	Sepphoris	"	2.0817	0.84468
A27c	"	"	2.0767	0.83926
Ap6a	Ophel	"	2.0865	0.84514
Ap9b	"	"	2.0868	0.84725
Teutsch (2001)				
Sample		Material	$^{208}Pb/^{207}Pb$	$^{207}Pb/^{206}Pb$
SHO-4-1		humus soil	2.069	0.8467
SHO-4-2		"	2.071	0.8496
SHO-4-3		"	2.064	0.8446
SHO-4-4		"	2.064	0.8424

distribution with four data point concentrations, **Group 1** cluster contains data points for plasters from the Jericho, one of two Sepphoris water installations, it also includes the points for the Jesus and James ossuaries' soils and Qumran water installation. It is remarkable that the soil fills from the Jesus and James ossuaries and plaster from a water installation at the Qumran archaeological site near the Dead Sea (installation No. 49, 85 ppm Pb in plaster (Shimron, 2003) have virtually identical Pb-isotopic values. Such values imply contamination by lead from an (isotopically) identical lead ore and/or an identical Pb-contaminated water source. All these fall well within the field of Pb isotope values obtained from Roman period metal artifacts excavated in Israel (Yahalom Mack et al., 2015) and references therein). **Group 2** cluster contains values for the EHT ossuaries, one of two (an industrial pool) Sepphoris plasters, plasters from two installations in Ancient (Roman period) Jerusalem and values for soil from the Mary ossuary. **Group 3** cluster envelops points for contaminated (including petrol Pb) soils and also values from the Akeldama hill soil (Figure 4b, Figure 4c). **Group 4** cluster is close to the range of lead from natural soils (Teutsch et al., 2001; Erel et al., 1997). It includes the non-poluted Talpiot hill, the Patio tomb and Mariamene ossuary soils.

3.3. Statistical Analyses of Major Element Assays

A classification problem analogous to provenancing the James ossuary is that of Mosteller and Wallace (Mosteller & Wallace, 1984) determining authorship of the disputed Federalist papers. We have used this analog as guidance in our efforts to use major element assays for classification. Our problem also closely resembles the common forensic problem of identifying the source of a soil or plant residue on a piece of crime evidence. In a recent publication of the Centre for Australian Forensic Soil Science, R. W. Fitzpatrick and M. D. Raven (Fitzpatrick & Raven, 2016) state: "In essence, forensic soil scientists and geologists must determine if there are unique features of soils or geological materials crucial to an investigation that enables these soils to be compared with soils from known locations. To achieve these objectives, there are various approaches, stages and steps for ensuring that this is achieved but there is no 'authoritative scene of crime manual or laboratory methods manual'. The approach and method of each forensic situation has to be taken on its merits according to existing conditions but must involve using standard approaches to record, describe and analysis materials …" Lark and Rawlins (Lark & Rawlins, 2008) have proposed the building of a soils chemical database which would help determine the provenance of soil evidence in a forensic investigation. Specifically they suggested a likelihood function with using elemental profile of the unknown sample compared to known elemental profiles at particular locations.

We have thought about how various groups of ossuaries might become chemically distinct from one another, and then applied methods done in standard

ways, to quantify these distinctions. **Figure 3** and **Figure 4** show that a statistical model should readily distinguish members of the Talpiot group from random ossuaries. The TT ossuaries soil is enriched with Si, Al, Fe, K, Na and Mg when compared to soils taken from our random samples. Using all data from the three laboratories available for the major elements Al, Fe, K, Na and Mg, we first decided on three elements (Al, Fe, and K) exhibiting the largest discriminating factors—statistics indicating the elements having greatest difference between Talpiot and non-Talpiot groups. Using these we built a likelihood model based on a Student's t support function. We calculated parameters of a comprehensive multivariate model which includes estimated correlation among major element assays. We then calculated likelihood ratios of our samples, one each for GSI and Bergen analyses, of James ossuary soil fill material coming from either a Talpiot tomb-like ossuary or an ossuary with chemistry like the random group. Our result is a logarithm (base 10) likelihood of slightly less than to slightly greater than 4 depending on which assays for the James ossuary one chooses for comparison. A likelihood of this magnitude alone suggests our major element assays provide powerful evidence (see Royall, 1997 in regard to likelihood measuring evidence) for a Talpiot classification for the James ossuary. However, a useful example is to illustrate how such evidence should modify one's prior beliefs about membership. In this regard an assumed prior odds of 300:1 in favor of a non-Talpiot classification for the James ossuary, which is approximately the ratio of number of all known ossuaries to Talpiot ossuaries, with a log-likelihood ratio of 4 results in posterior odds above 30:1 favoring a Talpiot designation.

3.4. Factor Analysis

Factor analysis was carried out on log-transformed data of all Bergen University EHT group of soil fill samples analyses (using STATISTICA 12 [Stat soft]), as they are sourced from an identical geological-soil terrain as those from the Talpiot tomb. The analyses focused on the major and trace elements which originate only from the inorganic components of the soil (Si, Al, Fe, K, Na, Ca, Mg, Ti, Ba, Mn, Rb, Y, Zr, Nb, Cs and Hf). The phosphate fraction (bone and rock) and metals (Cu, Pb and Zn), most of which are suspected of having been contributed by pollution, were omitted. The analyses yield 2 factors which account for 89% of the variance. These factors can in major part be explained on the basis of the mineralogy and chemistry of the soil fill samples. They comprise: 1) elements derived from silicates and iron/titanium oxides; and 2) elements sourced by the presence of barite and other heavy minerals. The results, shown in **Figure 8** (**Table 4**), show the plots for the scores of factor I against factor II for the Talpiot tomb samples, samples from the EHT's, three of the Talpiot tomb ossuaries (Jesus, Mary and Mariamene Mara) and the James ossuary. The concentration, although showing a wide scatter, reveals the almost certain affiliation of the James ossuary with the Talpiot tomb.

Table 4. Major, trace element and REE chemical data used for Figure 8.

Sample	Si%	Al%	Fe%	K%	Na%	Ca%	Mg%	Ti%
S 2576 olive	4.08	0.83	0.69	0.19	1.72	30.04	0.60	0.10
S 2577 olive	5.70	1.11	0.83	0.21	0.01	27.82	1.11	0.11
S 876 kid	4.76	1.15	0.84	0.25	0.08	29.08	0.54	0.13
69 - 153 off	6.16	1.91	1.13	0.27	0.01	28.39	0.52	0.15
69 - 195 scop	6.93	0.90	0.60	0.16	0.08	28.02	0.18	0.09
69 - 686 fh	4.63	1.45	0.96	0.20	nd	29.11	0.49	0.14
71 - 429 ms	1.66	0.35	0.29	0.07	0.22	28.44	0.37	1.00
74 - 1502 ms	3.21	1.44	0.91	0.13	0.09	30.77	0.19	0.11
75 - 689 ms	6.58	1.26	0.98	0.29	0.03	21.70	0.71	0.16
80 - 515 et	6.15	1.33	0.97	0.22	nd	26.73	0.52	0.26
80 - 522 et	9.13	2.06	1.43	0.34	0.10	23.17	0.72	0.25
80 - 500 ttmmar	8.74	2.48	1.89	0.37	0.01	20.53	0.63	0.25
80 - 503 ttyesh	10.54	2.66	1.77	0.39	0.39	23.09	0.71	0.14
80 - 505 ttmir	7.63	1.74	1.37	0.31	0.11	22.61	0.45	0.20
AS 51 James	5.93	1.78	1.14	0.56	0.49	27.2	0.5	0.14
Sample	Bappm	Mnppm	Rbppm	Yppm	Zrppm	Nbppm	Csppm	Hfppm
S 2576 olive	135	104.0	5.50	5.95	17.77	2.50	0.29	0.50
S 2577 olive	236	200.7	12.18	15.14	47.39	6.10	0.69	1.33
S 876 kid	199	171.3	11.32	8.96	nd	4.81	0.57	0.55
69 - 153 off	159	223.1	14.58	17.25	68.94	8.91	0.97	1.91
69 - 195 scop	66	57.46	6.64	11.43	nd	2.59	0.46	0.33
69 - 686 fh	138	257.3	16.71	15.74	77.58	9.15	1.02	2.16
71 - 429 ms	99	38.32	2.23	4.49	nd	1.05	0.20	0.14
74 - 1502 ms	68	116.0	10.07	13.15	32.47	4.48	0.70	0.90
75 - 689 ms	276	193.1	14.10	11.58	36.54	6.07	0.74	1.02
80 - 515 et	159	109.2	8.83	12.42	28.36	4.66	0.46	0.65
80 - 522 et	167	164.7	16.46	27.83	52.68	7.02	1.04	1.43
80 - 500 ttmmar	205	421.4	26.92	25.11	126.4	16.39	1.38	3.49
80 - 503 ttyesh	199	400.6	25.16	24.42	131.8	15.42	0.98	3.66
80 - 505 ttmir	218	345.0	18.38	22.22	104.0	13.14	1.03	2.93
AS 51 James	350	353.1	18.76	11.17	nd	5.63	0.97	0.98

4. Discussion

Prior to discovery the Talpiot tomb ossuaries were completely buried by East Jerusalem's soils for some 1600 years. During this time some of the encapsulating soil invaded the ossuaries. Yet, in spite of being subtly modified by invasive dust, for most elements the chemical composition of the covering soil and that which invaded the ossuaries falls into well-defined compositional clusters implying a common geochemical history. In contrast, soils collected from random ossuaries throughout Jerusalem, including from geological terrain identical to the TT cluster (the EHT group), differ chemically while showing a broad spread in compositional values in addition to extensive anthropogenic contamination. Specifically, Pb-isotopes for soil fills from most EHT, Akeldama hill, and perhaps including the Mary, ossuaries fall into a compositional cluster indicative of lead contributed from what was probably a common anthropogenic (urban and Alkyl-Pb) source. The latter is well exhibited on the Jerusalem soil map; this resembles a mushroom-like shape of toxic fallout with concentrations of Pb (and other metals) in soils frequently in the range 40 - 380 ppm (Figure 2b). In addition, Pb-isotopic data (Figure 6) also provide evidence that occupants of some of the TT ossuaries may have consumed Pb-polluted water from identical sources such as the Pb-lined plumbing system in Roman-period Sepphoris and/or from Pb-enriched water sources elsewhere (e.g. Qumran).

While Figure 8 shows especially that various groups of ossuaries form a distinct population based on chemistry, it also shows a substantial scatter around a central measure. What is the source of this scatter? First, the analytical uncertainties of methods and equipment employed in the laboratories (<1%) is miniscule compared to the observed scatter. Thus, we conclude that the major source of uncertainty is that underlying the samples themselves magnified by sampling methods. For example, within the Talpiot tomb the sediment covering its ossuaries was not necessarily homogeneous being as it was a landslide mixed combination of soils, chalk, flint and marl. Each Talpiot tomb ossuary found itself covered by a broadly consistent material with a unique local (Talpiot hill) recipe. Among the Random ossuaries collected from many tombs airborne particles, and even airborne contaminants such as Alkyl-lead, are not necessarily identical from tomb to tomb due to location or construction. Moreover, the chalk and limestone comprising the ossuaries themselves may have come from various unique sources. Finally, when sediment fill had become cemented in some ossuaries, particularly in the Random group, the scraping needed to collect a sample probably contributed to some enrichment in Ca from the chalk, cementing flowstone and P from degrading bone accompanied by a decrease in clay-derived elements from dilution. Nonetheless, we have successfully demonstrated at first identifying physical mechanisms by which artifacts would evolve chemically along unique paths; and, then demonstrating that these expectations were borne out by chemical analyses. Perhaps this combination of broad geological considerations with analytical chemistry is a useful model to employ in the study of artifacts in general.

5. Conclusion

Of our stated objectives we conclude the following: First, the chemistry of the inorganic materials (mostly soils) which were flushed into the Talpiot tomb and ossuaries it held are distinct from other ossuaries removed from tombs in the Jerusalem area. Second, having evidence of the distinct chemistry of these soils, we have shown in several ways—factor analysis, likelihood analysis of major elements assays, isotope analysis, and through analysis of chemistry scatter-plots—a remarkable similarity between chemistry of the James ossuary and the Talpiot tomb group. One obvious conclusion is that the James ossuary is likely a member of the Talpiot group. However, being aware of the controversy surrounding both this tomb and this ossuary, we must suggest other possible explanations for this similarity. Two come to mind, which we can easily address.

The James ossuary may have obtained its chemistry in the courtyard of the antiquities dealer or even home of the antiquities collector, and this chemistry is *by chance* similar to that of the Talpiot tomb. We have no chemical data regarding the chemistry of airborn dusts in the Jerusalem area over the long-term, but we have analyzed a sample of such dust one of us (AES) collected after a major dust storm which struck the country in September 2015 ([Figure 3c](), [Table 2]()).

We found that this desert airborn dust is enriched in Si, Al, K, Fe and Mg and much impoverished in Ca relative to the Talpiot tomb, the James, all other ossuaries and most Jerusalem soils in general ([Figure 3c]()). Although showing some chemical similarity with the silicic flint-rich soil from the Patio tomb, it bears no resemblance to the chemistry of either the Talpiot tomb or to any soils from the Jerusalem area.

Another possible explanation is that the James ossuary actually belongs to the group of Random ossuaries and simply represents an outlier in their typical chemistry. Putting this possibility to test was our rationale for the *likelihood analysis* above. For this explanation to hold requires not only an outlier status for the James ossuary, but one that happens to map in the heart of the Talpiot group. The likelihood ratio argues strongly against such a coincidental occurrence.

A third possible explanation is more difficult to address. One might speculate that the James ossuary came from some yet unconsidered tomb with a disturbed environment, that is, a tomb breached with soils diluted with marl from the Talpiot hill. We know of no other such tomb except the Talpiot, but of such an alternative we can only conclude that time will tell.

Finally, we have shown that detailed chemical analyses of soils sampled from ossuaries can, within limits, be useful in provenancing such artifacts. Our conclusions are made possible here by the incidental coalescence of a number of geological phenomena: 1) the unique chalk-chert geochemistry of East Jerusalem's bedrock; 2) a powerful earthquake which shook the region in antiquity; and 3) the generation of tectonic slides one of which caused flooding and burial with soil of the Talpiot tomb and ossuaries therein. It is remarkable that the

ossuary of James, which must have followed a different evolutionary path for the latter 30 years of its existence, and in spite of the considerable contamination therein with metallic fragments, still manifests a unique geochemical signature consistent with the chemistry of other Talpiot tomb ossuaries.

Acknowledgements

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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