Journal of Archaeological Science 125 (2021) 105268

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Debasement of silver throughout the Late Bronze – Iron Age transition in the Southern Levant: Analytical and cultural implications

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ARTICLE INFO

Keywords:
Silver hoards
Alloys
Lead isotopic analysis
Debasement
Arsenic
Bronze age collapse
Mediterranean trade

ABSTRACT

The study of silver, which was an important mean of currency in the Southern Levant during the Bronze and Iron Age periods (~1950–586 BCE), revealed an unusual phenomenon. Silver hoards from a specific, yet rather long timespan, ~1200–950 BCE, contained mostly silver alloyed with copper. This alloying phenomenon is considered here for the first time, also with respect to previous attempts to provenance the silver using lead isotopes. Eight hoards were studied, from which 86 items were subjected to chemical and isotopic analysis. This is, by far, the largest dataset of sampled silver from this timespan in the Near East. Results show the alloys, despite their silvery sheen, contained high percentages of Cu, reaching up to 80% of the alloy. The Ag–Cu alloys retained a silvery tint using two methods, either by using an enriched silver surface to conceal a copper core, or by adding arsenic and antimony to the alloy. For the question of provenance, we applied a mixing model which simulates the contribution of up to three end members to the isotopic composition of the studied samples. The model demonstrates that for most samples, the more likely combination is that they are alloys of silver from Aegean-Anatolian ores, Pb-poor copper, and Pb-rich copper from local copper mines in the Arabah valley (Timna and Faynan). Another, previously suggested possibility, namely that a significant part of the silver originated from the West Mediterranean, cannot be validated analytically. Contextualizing these results, we suggest that the Bronze Age collapse around the Mediterranean led to the termination of silver supply from the Aegean to the Levant in the beginning of the 12th century BCE, causing a shortage of silver. The local administrations initiated sophisticated devaluation methods to compensate for the lack of silver – a suspected forgery. It is further suggested that following the Egyptian withdrawal from Canaan around the mid-12th century BCE, Cu–Ag alloying continued, with the use of copper from Faynan instead of Timna. The revival of long-distance silver trade is evident only in the Iron Age IIA (starting ~950 BCE), when silver was no longer alloyed with copper, and was imported from Anatolia and the West Mediterranean.

> “בֶּן-אָדָם, הָיוּ-לִי בֵית-יִשְׂרָאֵל לסוג (לְסִיג): כֻּלָּם נְחֹשֶׁת
> וּבְדִיל וּבַרְזֶל וְעוֹפֶרֶת, בְּתוֹךְ כּוּר–סִגִים כֶּסֶף, הָיוּ.”
>
> “Son of man, the house of Israel has become dross to me; all of them are bronze and tin and iron and lead; in the furnace they are dross of silver.” (Ezekiel 22, 18; ESV)

1. Introduction: Background and aims

Over 35 silver hoards were unearthed in the Southern Levant, dating from the Middle Bronze Age to the end of the Iron Age (~1950–586 BCE; Eshel et al., 2018; Eshel, forthcoming, with references therein). The hoards contain mostly cut ingots and broken jewelry, which served as a form of currency, and provide a large and extendable dataset for silver provenance (see more in Appendix B). Since silver does not occur locally in the Levant, silver items from these hoards were analyzed to trace the

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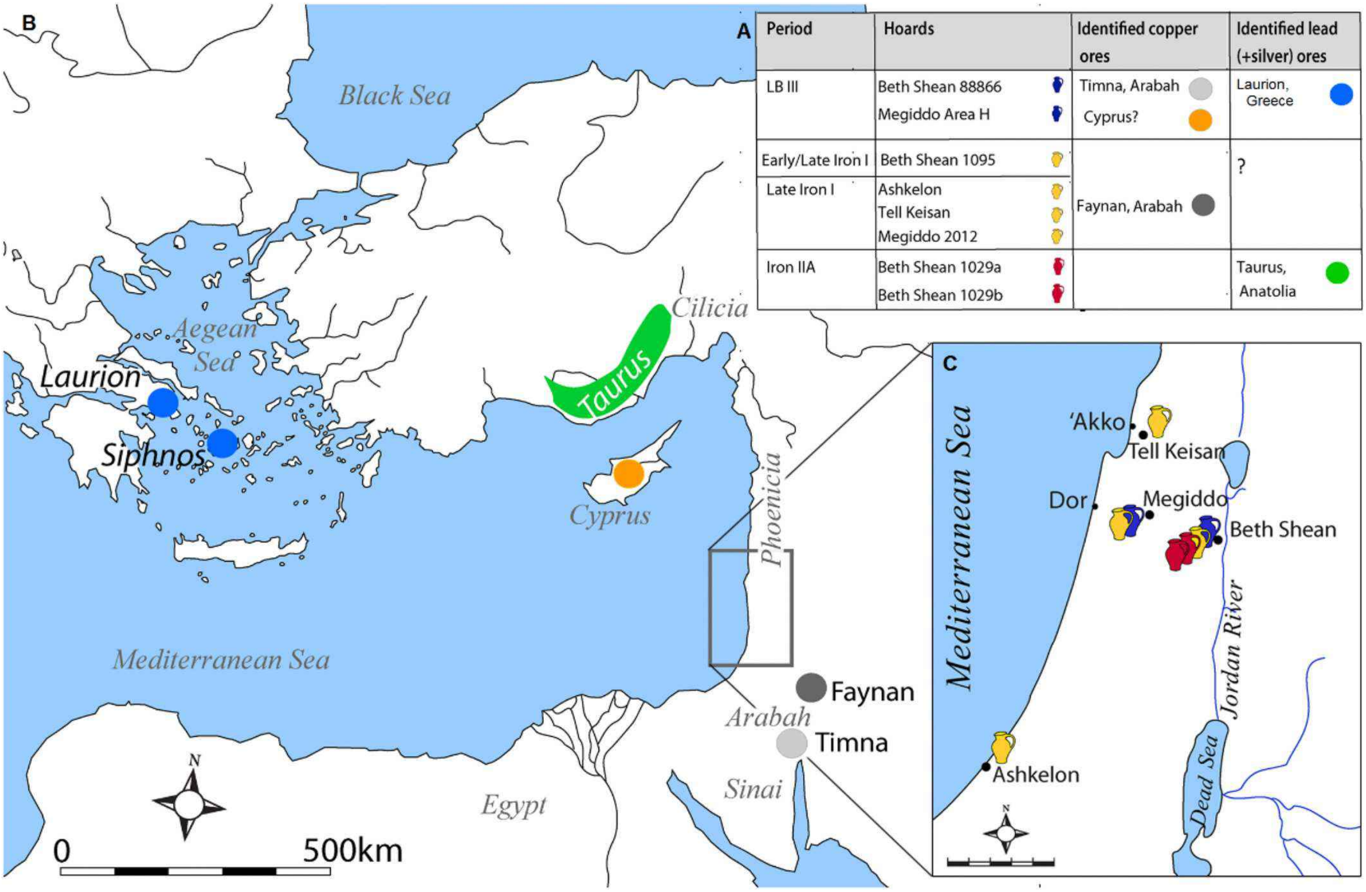
https://doi.org/10.1016/j.jas.2020.105268
Received 26 February 2020; Received in revised form 22 October 2020; Accepted 26 October 2020

changing sources of silver imported to the Southern Levant during these periods. Lead-isotope results obtained from two silver hoards from the Southern Levant were published for the first time by Anna-Zofia Stos-Gale (2001). Subsequently, Christine Thompson in her PhD thesis (2007) discussed the provenance of silver items from ten additional Iron Age silver hoards (ca.1200–600 BCE). The dissertation is based on the suggested provenance of 147 samples analyzed for Pb isotopic ratios in the Isotrace Laboratory at the University of Oxford by Stos-Gale. The results are available online, accompanied with bulk chemical compositions (Au, Pb and Cu wt.%, obtained by XRF) in the OXALID database. These results were previously discussed (Thompson and Skaggs, 2013; Martín Hernández, 2018; Wood et al., 2019). Recently, we significantly enlarged the number of lead-isotope analyses obtained from South Levantine hoards (~250 additional analyses), and measured detailed chemical compositions (Eshel, forthcoming). By intertwining chemical and lead isotope analysis (LIA) of current and previously analyzed silver with precise archaeological, contextual and chronological data, we aim to reveal commercial connections and incentives which could not have been previously identified. Using a similar methodology we were previously able to show that early Phoenician ventures to the West, to Sardinia and later Iberia (respectively in the 10th and 9th centuries BCE), were stimulated by the quest for silver (Eshel et al., 2019; see more in 4.2).

In the framework of the ~1500 years which we study, an unusual phenomenon emerged. We noticed that in a specific timespan, ~1200–950 BCE, all investigated hoards (n = 6) contain mostly silver alloyed with copper, while all other hoards, predating and postdating this timeframe, contained mainly pure silver. The alloys, despite their silvery sheen, reveal high percentages of Cu, reaching up to 80% (cf. Thompson, 2009; Eshel et al., 2018; Shalev et al., 2014; Yahalom Mack et al., in press). We suggest that this indicates intentional alloying as a result of a shortage in silver. This apparently was not a local phenomenon, since, for example, documents from Post-Kassite Babylonia (12th–10th centuries BCE), also suggest shortage in silver (Kleber, 2016). Indeed, the years between ~1200 and 950 BCE witnessed dramatic transformations around the Mediterranean following the 'Bronze Age collapse' (Cline, 2014 and see section 5). The direct contacts that Egyptian elites maintained with Mycenaean 'palaces' during the Late Bronze Age, exchanging, inter alia, Egyptian gold for Laurion silver, have ceased (Gale, 1980; Gale and Stos-Gale, 1981; Stos-Gale and Gale, 1982; Gill, 2010; Kelder, 2016), and the following period differed dramatically.

Here, thus, we follow the Late Bronze Age/Iron Age transition from the silver perspective. We apply a geological model for determining the provenance of silver alloys, which quantifies the addition of lead contributed by the added copper, thus enabling us to assess the source of the silver (and copper) in the alloy. In this manner we overcome a major limitation which lies in the heart of the suitability of LIA to determine the provenance of metals in alloys, in this case silver and copper (for general discussions on demerits of the LIA method, see Knapp, 2000; Pollard, 2009; Radivojević et al., 2018; Eshel et al., 2019).



Period	Hoards	Identified copper ores	Identified lead (+silver) ores
LB III	Beth Shean 88866 Megiddo Area H	Timna, Arabah ● Cyprus? ●	Laurion, Greece ●
Early/Late Iron I	Beth Shean 1095	Faynan, Arabah ●	?
Late Iron I	Ashkelon Tell Keisan Megiddo 2012		
Iron IIA	Beth Shean 1029a Beth Shean 1029b		Taurus, Anatolia ●

Fig. 1. (a) Relative and absolute chronology of the hoards mentioned in the paper and suggested provenance of the contained silver and copper in them. (b) The East Mediterranean Sea, lead and copper ores, and other locations referenced in the text. Lead ores: blue - The Aegean; green - Anatolia. Copper ores: orange- Cyprus; greyscale - Faynan and Timna. (c) Location of hoards mentioned in this study. Maps by Svetlana Matskevich. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

2. Materials and methods

2.1. The data set

Eighty-six samples from eight hoards from various sites in the Southern Levant were subjected to chemical and isotopic analysis (see locations in Fig. 1). The content, context and chronology of the hoards and items are presented in Appendix A. The typology of silver items is described in Eshel et al. (2018).

2.2. Chronology

In an attempt to show possible developments and changes in silver sources and trade during the period under investigation, it is pertinent to date the hoards with the best possible resolution. Stratigraphic and archaeological contexts of the silver hoards were, therefore, reconsidered based on previous publications and personal communications with the excavators, including reassessments of contexts and dates when needed (presented in Appendix A).

The terms used for relative chronology in the Southern Levant ~1200–950 vary between sites and scholars, as summarized in Table A.1. Here we employ the terminology used at Megiddo (Toffolo et al., 2014). In the Levant, this timespan can be divided roughly into three periods: Late Bronze Age III (LB III), and Early and Late Iron Age I. The LB III (~1200–1150 BCE) is the swansong of Egyptian rule in the Levant (e.g., Singer, 1988). The following Early and Late Iron Age I (~1150–1050 BCE and ~1050–950 BCE respectively) exhibit a gradual recovery, culminating in an urban climax (see section 5). These periods are usually described in terms of ethnogenesis (Philistines, Israelites, Phoenicians), while the commercial aspects are often neglected (but cf., for example, Sherratt, 1998; 2012; Aubet, 2008; Kourou, 2008; Bell, 2009; Sader, 2019).

2.3. Chemical analysis

Sample preparation, chemical and LI analysis were performed in the clean laboratory of the Institute of Earth Sciences at the Hebrew University of Jerusalem, according to the procedures described in Eshel et al. (2019). The precision and accuracy of the measurements of elemental concentrations by ICP-MS (Agilent; 7500cx), were ±5%.

The measured elements were silver (Ag), copper (Cu), lead (Pb), arsenic (As), antimony (Sb), gold (Au), bismuth (Bi), nickel (Ni), zinc (Zn) and iridium (Ir). The chemical compositions are used primarily for identifying mixing and alloying, rather than for sourcing the ores (see Appendix B).

2.4. Lead Isotope (LI) analysis

Isotopic measurements were conducted with a MC-ICP-MS (Thermo Neptune Plus). Replicate measurements of National Institute of Standards and Technology (NIST) SRM-981 standards yielded over the course of this study mean values of $^{206}Pb/^{204}Pb = 16.931 \pm 0.005$, $^{207}Pb/^{204}Pb = 15.483 \pm 0.006$, and $^{208}Pb/^{204}Pb = 36.674 \pm 0.013$ (2σ, $n = 53$).

The LI results were used to identify silver ore sources. For a full explanation of the methodology, its limitations, and for the graphic representation of the two-stage geological model on which the results are plotted, see Eshel et al. (2019). Employing the methodology discussed in the latter publication, we differentiate between two categories of results: (a) Endmembers. These are two groups of items, with two distinct isotopic ratios, which cluster at the two extremes of the LI values, plotting along or near a Pb–Pb isochrone (Eshel et al., 2019); (b) Mixed and unidentified artefacts. The isotopic ratios of these items fall between the endmembers (i.e., crossing Pb–Pb isochrones), and they either reflect mixing of the endmembers, or a contribution from one or more unknown sources. Additional LI measurements of 20 items from some of the hoards included in this study had been previously obtained by Christine Thompson (2007; 2009) and analyzed by Stos-Gale (five from the BS 88866 hoard, seven from the Ashkelon hoard and eight from the Tell Keisan hoard, available online on OXALID - http://oxalid.arch.ox.ac.uk). We consider these samples in our discussion and conclusions, yet they are not presented here since their chemical composition (Au, Cu and Pb), which is essential for this study, was measured using XRF, which has significant detection and calibration limitations (see more in Eshel et al., 2018).

2.5. A mixing model for provenancing Cu–Ag alloys

A mixing model for coping with the problem of provenancing Ag–Cu alloys was applied (Frisch et al., 1985: 355–356; for the application in archaeology see Beherec et al., 2016: 79). This is the first application of the mixing model for Ag–Cu alloys, and the first study to consider the problem of alloying in relation to Pb-rich copper ores in the Levant. The caveat is that the lead contents in the Ag–Cu alloys cannot serve *sensu stricto* as an indication for the addition of Pb-rich copper. This is because Pb concentrations in silver vary widely, depending on the quality of the cupellation process (e.g., Pernicka and Bachmann, 1983; Eshel et al., 2019). We thus base our analysis on a combination of lead isotopic ratios, chemical compositions and careful selection of possible endmembers, implementing a mixing model composed of three endmembers, a, b and c, which represents copper and lead ores. The model is computed based on three equations, where X, Y and Z are the fractions of each endmember in the alloy, respectively (see Fig in 3.3.2).

(1) $[Cu]sample = X^*[Cu]a + Y^*[Cu]b + Z^*[Cu]c$

(2) $[^{206}Pb]sample = X^*[^{206}Pb]a + Y^*[^{206}Pb]b + Z^*[^{206}Pb]c$ $[^{204}Pb]sample = X^*[^{204}Pb]a + Y^*[^{204}Pb]b + Z^*[^{204}Pb]c$, once both $[^{206}Pb]$sample and $[^{204}Pb]$sample are calculated, they are divided to obtain $^{206}Pb/^{204}Pb$ in the sample.

(3) $X + Y + Z = 1$

The model uses the Cu, Ag, Pb concentrations and LI average compositions of specific ores as endmembers and calculates expected LI ratios and Cu concentrations of the Cu–Ag alloys created from a mix of metals from these ores. The choice of the endmembers was determined based on archaeological and historical–geographical considerations and several alternatives are presented.

3. Results

3.1. Context, content and chronology of the hoards

Our chronological examination (Appendix A) reveals that the eight silver hoards presented in this paper (Figs. 1 and 2) can be divided into three chronological groups: Two hoards date to LB III (BS 88866, Megiddo H) and are associated with the last phase of the Egyptian presence in the region (~1200–1150 BCE; the early 20th Egyptian Dynasty). They were unearthed in or near palatial/public contexts, demonstrating that the silver in these sites was associated with the elite sphere (Vargyas, 2000; Eshel et al., 2018; and see more in 5). One hoard dates either to the Early or Late Iron Age I, ~1150–1050 BCE or ~1050–950 BCE respectively (BS 1095). Three hoards date unequivocally to the Late Iron Age I, ~1050–950 BCE: Ashkelon, Megiddo 2012, Tell Keisan). Notably, the Ashkelon hoard is attributed to the last of three Iron I sub-phases at the site (see Appendix A). In order to simplify, BS 1095 is clustered with the Late Iron Age I. These four hoards were found in domestic, industrial, or market contexts (see table A.2 and more in section 5).

Lastly, two hoards from Beth Shean (BS1029a, BS1029b) date to the Iron Age IIA (~950–800 BCE) and are thus later than the temporal focus of this paper. They are included here to provide a long-term perspective of the earlier hoards, and among other things, they serve as a

Fig. 2. The silver hoards analyzed in this study, according to chronological order: LB III: (a) Beth Shean 88866 silver hoard, courtesy of the Beth Shean expedition. (b) Analyzed items from Megiddo Area H bundle, courtesy of Eran Arie and the Megiddo Expedition. Early/Late Iron Age I: (c) Silver from the Beth Shean 1095 hoard, photographed by Ivgeni Ostrovski. (d) Silver from the Megiddo 2012 hoard, photographed by Clara Amit. Late Iron Age I: (e) Silver from the Tell Keisan hoard, before and after cleaning, photographed by Yael Yolovich (and not by Clara Amit) (f) Silver from the Beth Shean 1029a hoard, photographed by Ivgeni Ostrovski. (g) Silver from the Beth Shean 1029 b hoard, photographed by Ivgeni Ostrovski. Photos (c)–(g) are courtesy of the Israel Antiquities Authority.

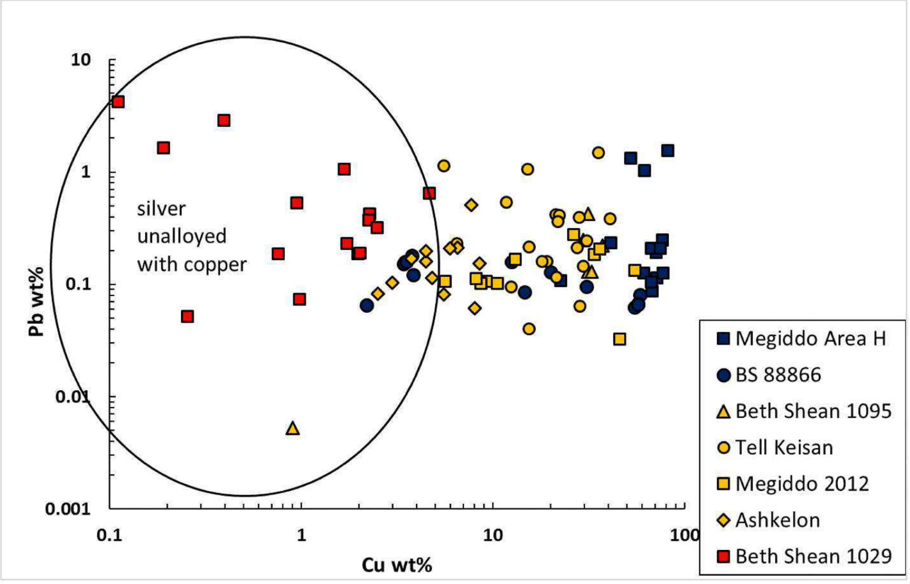


Fig. 3. Pb vs Cu concentrations. LB III silver items are in blue, Late Iron Age I silver items are in yellow, and Iron Age IIA in red. The ellipse marks chemical ratios expected for silver unalloyed with Cu. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

chronological limit for the extent of silver debasement and its provenance. These Beth Shean hoards were not included in Eshel et al. (2019) that dealt with Iron Age IIA, since the re-examination of their context/chronology and concomitant realization that they belong to that period came after the publication of the paper (see Appendix A).

The contents of the hoards show a typological shift from broken jewelry in bundles during LB III and Late Iron Age I to the use of 'cut ingots' without cloth bundles in the Iron Age IIA, in accordance with previous studies (Table A.2; Eshel, 2014; Eshel et al., 2018).

3.2. Chemical composition

Eighty-six items were examined for chemical composition. The most striking observation is that 80% of the sampled items from the LB III–Iron Age I silver hoards (n = 57/71) have significant concentrations of copper and elements other than silver, while 100% of the sampled items from the Iron Age IIA hoards contain silver unalloyed with copper (n = 15; Figs. 3 and 4 and Table B.1). In order to provenance these items using lead isotopes, we distinguished between two compositional groups (for the criteria see Pollard and Bray, 2015; Eshel et al., 2019 and Appendix B.2.1) (1): silver unalloyed with copper (Cu<5.5%) and (2) silver-copper alloys (Cu>5.5%). For each group, the LI composition in the items is presented (sections 3.3.1 and 3.3.2 below). Finally, using a mixing model, the Cu concentrations are combined with LI ratios in order to identify and tell apart the sources of Ag and Cu (section 3.3.2.3 below).

3.2.1. Silver unalloyed with copper

Of the 71 LB IIII–Late Iron I sampled items, only 14 contain less than 5.5% Cu and minimal traces of trace metals which are removed by cupellation (As, Sb, Sn, Ni and Zn; see Table A.1). These items were therefore identified as silver unalloyed with copper (Fig. 3). Seven of them date to LB III (from BS 88866; the other items in this hoard are copper cores with silver surfaces, see 3.2.2), and seven items date to the Iron Age I (six from Ashkelon and one from Beth Shean; Figs. B.1, 3). In contrast, as mentioned, *all* silver items from the Iron Age IIA (n = 15, from BS 1029a, b) are included in this group (Fig. 3).

3.2.2. Silver–copper alloys

Fifty-seven out of 71 items in the LB III–Late Iron Age I hoards are rich in copper (>5.5%) and contain noticeable amounts of metals which are typically removed by cupellation (As, Sb, Sn, Ni and Zn; see also Appendix B). This is the largest compositional group in this study, 16/23 from the LB III and 41/48 from the Late Iron Age I (Table B.1; Fig. 3). This phenomenon was not observed in silver hoards from other periods (MB IIB–LB I- Eshel et al. forthcoming; LB IIB- Yahalom-Mack et al., 2019; Iron Age IIA- Eshel et al., 2019 and the BS 1029a, b, hoards in this study; and yet unpublished Iron Age IIB and Iron Age IIC results- Eshel, forthcoming), demonstrating that the addition of Cu is a unique temporal phenomenon specific to the LB III–Iron Age I. Notably, LB III hoards have consistently high Cu concentrations ([Cu]>20% for most items), while Cu concentrations in Late Iron Age I hoards are more varied (Fig. 3). Bismuth and (high) gold concentrations have negative correlations with Cu, suggesting that they came with the silver and were diluted by Cu additions (see Appendix B). Fourteen out of 48 items from Iron Age I have high gold concentrations (>0.5 wt%), suggesting a wide extent of mixing and re-melting of jewelry (see more in 4.1).

Of the Ag–Cu alloys, 37 items contain more than 20% Cu, and are mostly associated with high As and Sb concentrations (30 items; As ranges between 0.5 and 5%; Sb ranges between ~100 and 2500 PPM; Fig. 4, B.1). These include 12/13 items from Megiddo H, 5/6 from BS 1095, 9/19 from Tell Keisan, and 4/11 from Megiddo 2012). We suggest, with caution, that these ratios may indicate a chronological trajectory: Silver items in early hoards (Megiddo H and possibly BS 1095) are regularly mixed with large amounts of As, while in later hoards (Tell Keisan, Megiddo 2012) As concentrations vary and are generally lower; The highest Cu, As and Sb concentrations were measured in the Megiddo H LB III hoard (Fig. 4, B.1). A linear correspondence was found between Cu and As in these 30 artefacts with a slope of 6%, almost identical to the miscibility of As in Cu (Fig. 4, see more in 4.1).

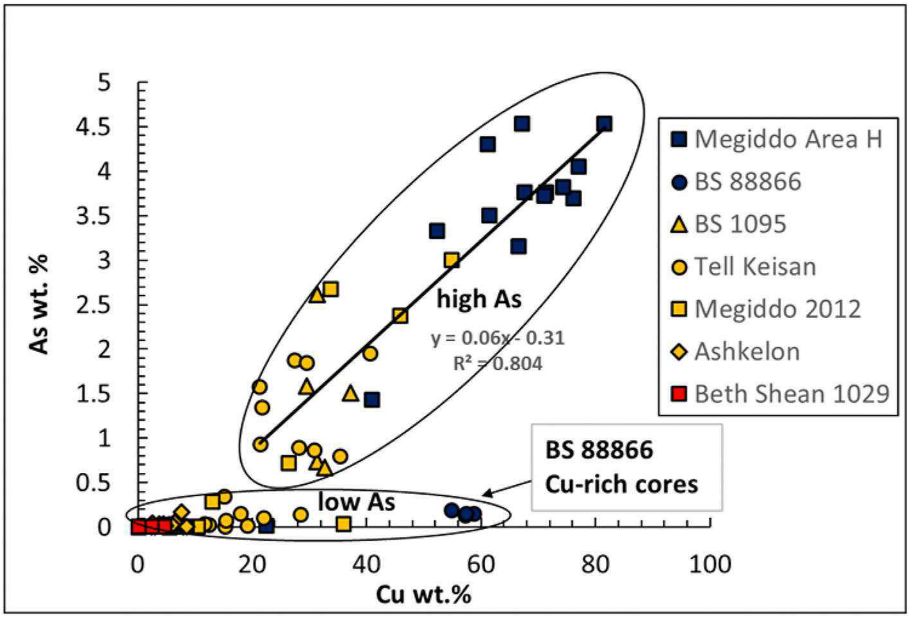


Fig. 4. Arsenic vs Cu concentrations. LB III silver items are in blue; Late Iron Age I silver items are in yellow. Iron Age IIA silver items in red. The ellipses mark high and low As concentrations. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Fig. 5. A section of 'cut-ingot' with hidden Cu-rich core, courtesy of the Beth Shean Expedition.

Seven artefacts have high Cu concentrations ([Cu]>20%), yet relatively low As and Sb concentrations. Three of these are 'cut ingots', from hoard BS 88866, which revealed copper cores upon cutting (Thompson, 2009). These were sampled twice, once at the surface and again at the core. Results indicate that the copper is not evenly distributed in these artefacts (as already suggested by Thompson, ibid.), being more concentrated in the core of the items ([Cu] = 55–60 wt%), than on the surface ([Cu] = 12–20 wt%; see Table B.1, Fig. 5; surface compositions are not presented on the graphs).

3.3. *Provenance*

The sources we propose for the analyzed items are presented according to the chemical groups defined above and within each group, chronologically. In Figs. 5–7 the periods are indicated by different colors.

3.3.1. *Silver un-alloyed with copper*

The 29 unalloyed silver objects (7/10 from BS 88866, 6/12 from Ashkelon, 1/6 from BS 1095 and 15/15 from BS 1029) are the only items in which the silver can be traced directly using LIA, since they were probably not affected by contribution of Pb from added copper (Fig. 6). Of these, 25/29 items plot within the isotopic range of Anatolian and Aegean ores (that belong to the young Alpine Orogeny; Tischler and Finlow-Bates, 1980).

3.3.1.1. LB III. Seven rods and broken jewelry items from the BS 88866 hoard fall in this category. Of these, four items (three rods and one earring: BS_88866_2, BS_88866_4, BS_88866_15, BS_88866_13) form a tight isotopic cluster and endmember consistent with Laurion, Attica (Gale and Stos Gale, 1981; Stos-Gale and Gale, 1982). A broken jewelry item (BS_88866_6) is probably also an endmember (see 3.3.2.1 below), the silver being consistent with Siphnos ores (Gale and Stos Gale, 1981; Stos-Gale and Gale, 1982) and with the Taurus 2 A ore in Anatolia (Yener et al., 1991; Sayre et al., 1992).

3.3.1.2. Late Iron Age I. One 'cut ingot' (BS 1095_3) is consistent with lead ores in Kirki in the Rhodope mountains, Northeast Greece; Stos-Gale and Gale (1982), however a single item is not enough to determine origin. Six items from the Ashkelon hoard create a mixing line. One endmember item (Ashkelon_7) is consistent both with Laurion and Taurus ores. The second endmember (Ashkelon_4) is consistent with ores from Sulcis, Sardinia and the Pyrite Belt, Iberia, which overlap. Three additional items from Ashkelon plot beyond the isotopic range of Anatolian and Aegean ores (Ashkelon_1, Ashkelon_3, Ashkelon_9). These four items are, therefore, the earliest evidence for West Mediterranean silver in the Levant.

3.3.1.3. Iron Age IIA. Fifteen ingots, cut ingots and rods from the BS 1029 hoards are included here. Five samples form an endmember cluster consistent isotopically with the Taurus 1 A ores in the Bolkardag mountains in Anatolia, similarly to silver in the other (Early) Iron Age IIA hoards we sampled (Eshel et al., 2019). The remaining items from these hoards do not form a clear second endmember. One item, which

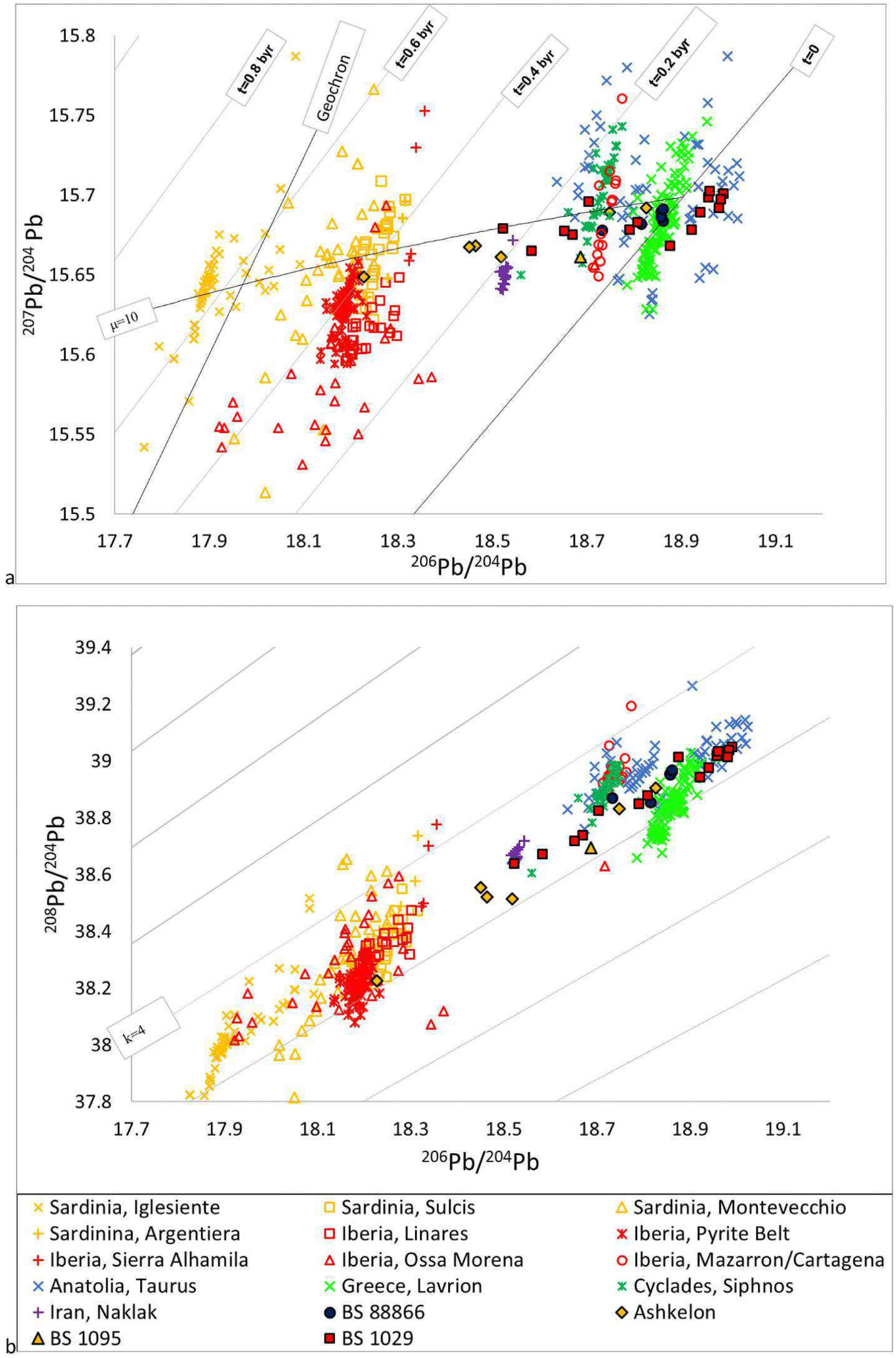


Fig. 6. (a) $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ of silver, unalloyed with copper, of the Beth Shean 88866, Beth Shean 1095, Ashkelon and Beth Shean 1029 hoards. (b) $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ of silver, unalloyed with copper, of the same hoards (Table B.1). LB III silver items are in blue, Late Iron Age I silver items in yellow, and Iron Age IIA items in red. The results are plotted against model ages of the major silver sources in the Near East and around the Mediterranean potentially exploited for silver in the Bronze and Iron Ages. Colors of lead ores are distributed geographically: Red – Iberia (Linares, Pyrite belt, Sierra Alhamila, Ossa Morena and Mazzaron/Cartagena; Graeser and Friedrich, 1970; Stos-Gale, 2001; Tornos and Chiaradia, 2004; Murillo-Barroso, 2013); Yellow – Sardinia (Igelsiente, Sulcis, Montevecchio and Argentiera; Boni and Koeppel, 1985; Stos-Gale et al., 1995; Begemann et al., 2001; Valera et al., 2005); Purple –Iran, Naklak (Nezafati and Pernicka, 2012); Blue – The Aegean (Laurion and Siphnos; Gale and Stos-Gale, 1981; Stos-Gale and Gale 1982) and Green – Anatolia, Taurus (Yener et al., 1991; Sayre et al., 1992). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

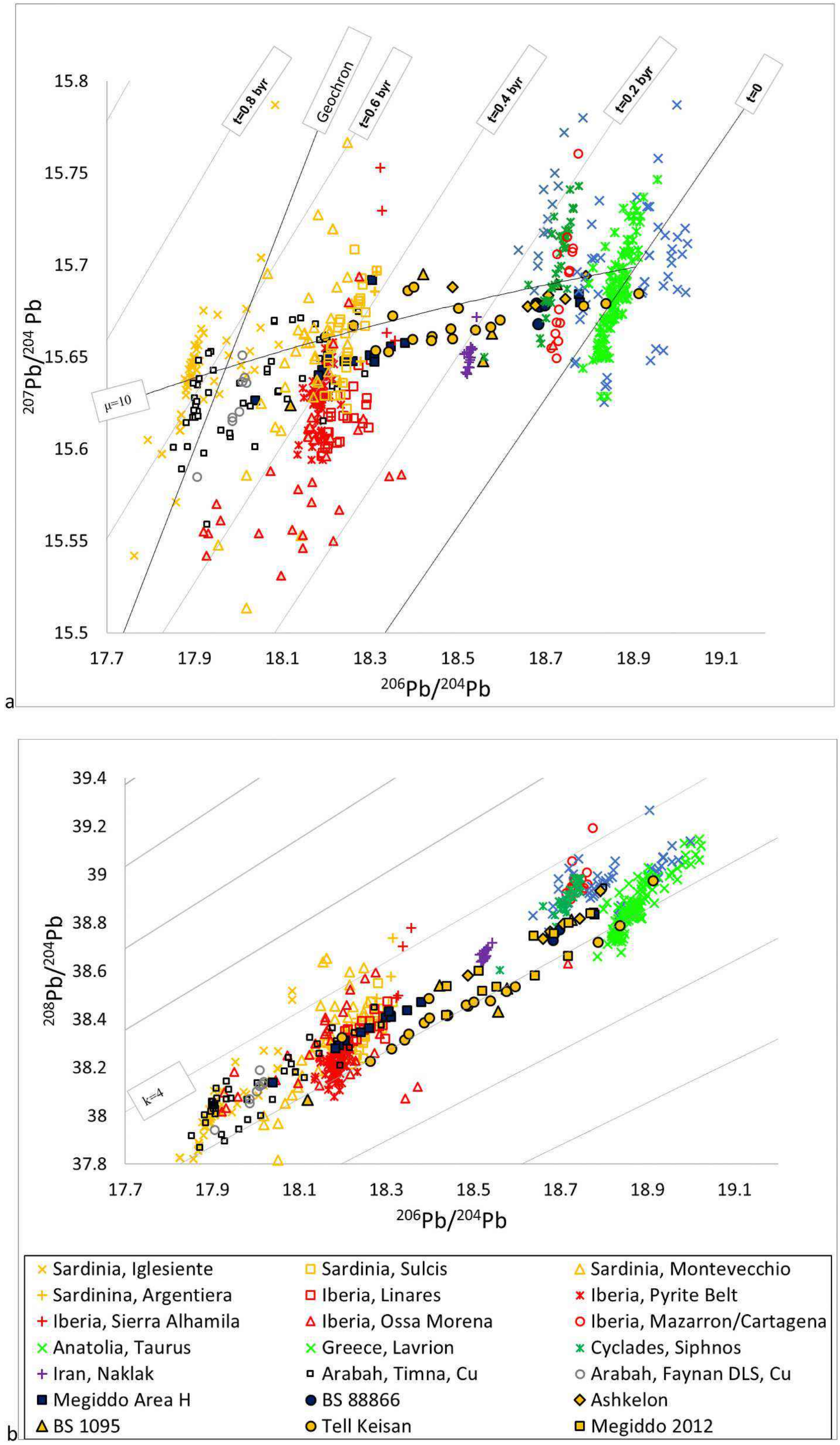


Fig. 7. (a) ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb of Ag–Cu alloys, of the Megiddo H, Beth Shean 88866, Ashkelon, Beth Shean 1095 Tell Keisan and Megiddo 2012 hoards. (b) ^{208}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb of Ag–Cu alloys, of the Megiddo H, Beth Shean 88866, Ashkelon, Beth Shean 1095 Tell Keisan and Megiddo 2012 hoards (Table B.1). LB III silver items are in blue and Late Iron Age I silver items are in yellow. The results are plotted against model ages of the major silver sources in the Near East and around the Mediterranean potentially exploited for silver in the Bronze and Iron Ages, as listed in Fig. 6. In this Figure, black and grayscale are used to represent the isotopic fields of copper ores in the Arabah (DLS in Faynan and Amir and Avrona formations in Timna; Gale et al., 1990; Hauptmann et al., 1992; 2007). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

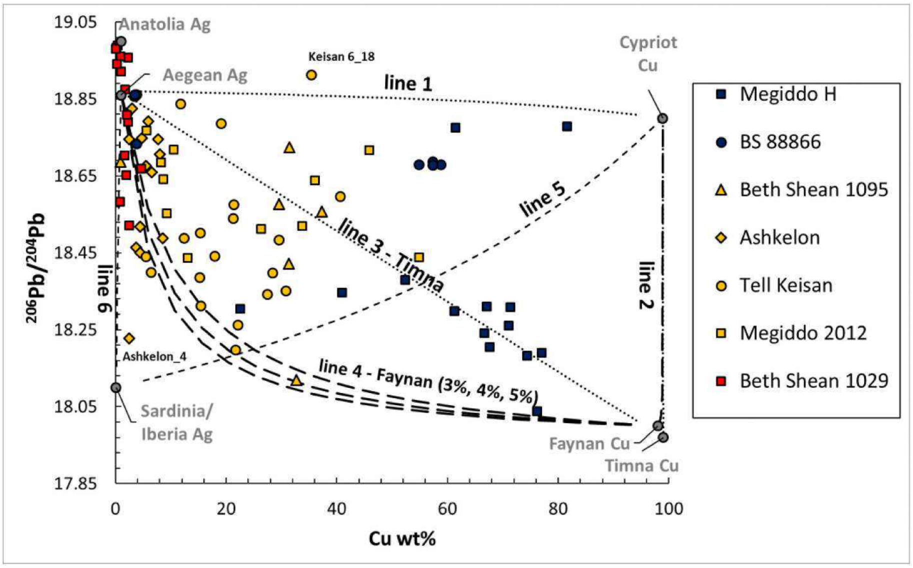


Fig. 8. $^{206}Pb/^{204}Pb$ vs. Cu concentrations in LB III, Late Iron Age I, and Iron Age IIA items compared with the different mixing lines. The two-endmember prediction limits of each model are marked with lines in the figure. Line 1: Aegean Ag – Cypriot Cu; Line 2: Cypriot Cu – Arabah Cu; Line 3: Aegean Ag – Timna Cu; Line 4: Aegean Ag – Faynan Cu. Line 5: Sardinian Ag – Cypriot Cu. Line 6: Aegean Ag – Sardinian Ag. Lines 1, 2, 3 border the area of mixing Aegean Ag – Cypriot Cu – Timna Cu. Lines 1, 2, 4 define the borders of the area of mixing Aegean Ag – Cypriot Cu – Faynan Cu.

has the lowest radiogenic isotopic values (BS1029_14), plots outside the isotopic field of most Anatolian and Aegean ores, but we could not positively determine the origin of the silver. This item might, for example, contain silver from Iran (Fig. 6).

3.3.2. *Silver–copper alloys*

Fifty-seven items dating to the LB III and Late Iron Age I are mixed with copper (Fig. 7).

3.3.2.1. LB III. There are 16 such items from two hoards (3/10 from BS 88866 and 13/13 from Megiddo H). In the BS 88866 hoard, the isotopic compositions of three copper-rich cores and their silver-rich exterior (BS 888866_ 24, BS 888866_25, BS 888866_27) are consistent with Siphnos ores and Anatolia (Taurus 2 A) ores, which overlap (Fig. 7). They have similar isotopic values in the core and exterior part (Table B.1), which are consistent with the endmember of the one unalloyed silver item from this hoard. This suggests that the added copper did not affect the isotopic compositions of the alloys, probably since the copper was low in lead (see more in 4.2). The items from the Megiddo H hoard form a long mixing line, with two endmembers (Fig. 7). One consists of two items (Megiddo H_15 and Megiddo H_26), which fall between the isotopic composition of several Anatolian and Aegean ores (Yener et al., 1991; Gale and Stos Gale, 1981). The second endmember consists of one item (Megiddo H_28), which is consistent with copper ores from the Arabah (Timna and Faynan; Gale et al., 1990; Hauptmann et al., 1992; 2007), and also with Ag-rich Cambrian lead ores of Sardinia, Iglesiente (Boni and Koeppel, 1985; Begemann et al., 2001; Valera et al., 2005).

3.3.2.2. Late Iron Age I. Forty-one items from four hoards belong to this category (6/12 from Ashkelon, 5/6 from BS 1095, 19/19 from Tell Keisan and 11/11 from Megiddo, 2012). The items from these hoards form similar mixing lines across the graph (Fig. 7a), with two endmembers. One falls in the Anatolian-Aegean region, and the other, comprising one item only (BS 1095_5), falls to the left of Hercynian lead ores from Iberia (Pyritic belt and Linares, Fig. 7) and Sardinia (Montevecchio, Argentiera and several ores from the region of Sulcis, Fig. 7), suggesting that its isotopic composition results either from copper ores in the Arabah or from lead ores from Iglesiente, Sardinia (see references in 3.3.2.1).

Twenty two out of 41 Late Iron Age I Ag–Cu alloys have lower $^{208}Pb/^{204}Pb$ values compared with LB III silver and silver-copper alloys, forming a parallel low-line in Fig. 6b, not apparent in the LB III. This suggests that an additional endmember source contributed lead to the alloys in this later period (see more in 3.3.2.3).

3.3.2.3. Sourcing Ag–Cu alloys. The Ag–Cu group differs isotopically from the unalloyed silver group in that nearly all the results which are consistent with either Sardinian lead ores or Arabah copper ores belong to this group (Figs. 5 and 6). This suggests that the 'Arabah/Sardinia' endmember might be related to the added copper.

Copper from Timna, and even more so from Faynan (both, as mentioned, located in the Arabah; Fig. 1) contains significant amounts of lead (~1%−5%; Hauptmann, 2007). Therefore, the addition of copper from the Arabah is expected to affect the Pb isotopic values of the alloy. Other copper ores in the region and beyond, including Sinai, Cyprus, Anatolia, Laurion and Sardinia, mostly contain only traces of Pb and are not expected to significantly affect the Pb isotopic composition of an alloy (Wagner et al., 1985, 1986; Stos-Gale et al., 1997; Begemann et al., 2001; Abdel-Motelib et al., 2012; Hauptmann et al., 2002, 2007; Yahalom-Mack et al., 2014; Rademakers et al., 2017). Some ores in Sinai also contain significant amounts of Pb (Abdel-Motelib et al., 2012), but the published isotopic compositions for each ore are too few and too scattered to be considered.

In order to trace the origin of the silver in the alloyed items, we applied a mixing model (see section 2.5 and Fig. 8 below). Three combinations of endmembers were used in the model, bearing in mind the isotopic overlap between Sardinian silver and Arabah copper ores: (1) Laurion silver, Cypriot copper, and Timna copper; (2) Laurion silver, Cypriot copper, and Faynan copper; (3) Laurion silver, Cypriot copper, and silver from the West Mediterranean (Sardinia/Iberia which overlap). For the first endmember Laurion was selected since unalloyed silver in the Southern Levant during the LB IIB–LB III mostly originated from there (see above and Thompson 2009; Yahalom-Mack et al., 2019). For the second endmember Cypriot copper was chosen since Cyprus was the major copper ore source to the Levant in the Late Bronze Age (e.g., Kassianidou, 2008; 2013), but it could in fact be replaced by any other Pb-poor copper ore source (e.g., from Laurion or Anatolia; see references above). For the third endmember we present three options: Sardinian/Iberian Ag-rich lead ores, Timna copper ores and Faynan copper ores (Fig. 8). The values used as endmembers in the mixing model are based on previous publications (for references see section 3.3.2.1): Aegean silver: $^{206}Pb/^{204}Pb$: 18.86; Pb: 3000 PPM; Cyprus copper: $^{206}Pb/^{204}Pb$:

18.5; Pb: 500 PPM; Faynan copper: ^{206}Pb/^{204}Pb: 18.0; Pb: 3%, 4%, 5% (three lines were drawn to fully represent the range of Pb in Faynan copper); Timna copper: ^{206}Pb/^{204}Pb: 17.97; Pb: 3000 PPM; Sardinia-Hercynian Cambrian silver: ^{206}Pb/^{204}Pb: 18.10; Pb: 2000 PPM. The model does not incorporate the addition of arsenical speiss, which was described in other studies as Cu-poor and Pb-poor (Thornton et al., 2009; Rehren et al., 2012). Therefore, it should not influence any of the parameters in the model (Cu% and ^{206}Pb/^{204}Pb).

The model demonstrates that even a small addition of copper from the Arabah has a substantial effect on lead isotopic values, yet it varies according to the specific source (Fig. 8). Although Timna and Faynan copper ores have similar LI values, their Pb contents differ: Faynan copper contains up to 5.5% Pb, and copper from Timna usually does not exceed 1.5% Pb (Hauptmann, 2007; Yahalom-Mack et al., 2014). Hence, contribution of Faynan copper to an alloy should affect the isotopic values more pronouncedly.

For the LB III, the model demonstrates that both Pb-poor and Pb-rich copper were added to the silver. All the items can be explained by an Aegean-Cyprus-Arabah mixture, while the Aegean-Cyprus-Sardinia mixture cannot account for 9/16 samples (Fig. 8), suggesting that the Arabah, rather than Sardinia, contributed lead to the low-radiogenic alloys. Furthermore, most of the samples plot along Line 1 (Aegean Ag-Cypriot Cu; two samples) and Line 3 (Aegean Ag-Timna Cu; 10 samples) in Fig. 8, suggesting that most items were produced using copper from only one source, mostly from Timna.

For the Late Iron I, the model is inconclusive regarding the question of whether Ag from the West Mediterranean or Cu from Faynan contributed to the isotopic composition of the alloys, as most items can be explained by both mixing combinations: Copper from Faynan can account for all Cu–Ag alloys, significantly excluding silver items unalloyed with copper (Ashkelon_1, Ashkelon_3, Ashkelon_4 and Ashkelon_9, see above 3.3.1.2). Sardinia or Iberia can account for the isotopic values of all alloyed and unalloyed samples except for BS 1095_5 (Fig. 8). Mixing and/or recycling is also evident, as most of the samples plot *between* the model lines, indicating that they include (at least) three different endmembers, possibly since they were alloyed more than once. Sardinia or Iberia, therefore, cannot be identified as definite sources of most silver in the Levant (see more in Section 5).

Finally, one Late Iron Age I item (Keisan 6_18), cannot be explained by the addition of Aegean Ag. It has more radiogenic ^{206}Pb/^{204}Pb values than any known Aegean ores, and can only be explained by contribution of Anatolian (Taurus 1 A) silver.

4. Discussion

4.1. Debasement (forgery?) of silver

Based on the results presented above, we argue that across the LB/Iron Age transition (~1200–950 BCE) silver in the Levant was substantially alloyed with copper. Out of 35 hoards spanning the Middle Bronze Age to the late Iron Age (~2000–600 BCE), only the hoards dated to this timespan contain mostly silver-copper alloys. The alloying of silver with copper-a much more readily available and cheaper metal than silver-indicates a need to overcome what appears to be a shortage of silver during this period.

Large amounts of copper (>20 wt% of the alloy) should have affected the color of the items significantly, making it reddish (Scott, 2011; Radivojević et al., 2018). In practice, however, all the items in this study had a silver tint on their surface after (greenish) corrosion was removed in the conservation process (e.g., Fig. 2a and c). This silvery appearance can be explained for most items by the segregation of deliberately added As and Sb upon cooling, eliminating the impact of copper on the color of the alloyed artefacts (Giumlia-Mair, 2008, 111; Mödlinger and Sabatini, 2016; Radivojević et al., 2018). We, therefore, suggest that As and Sb, which were rarely used in copper alloys later than the 4th millennium BCE (see further in Appendix B and in Section 4.1), were added to conceal the alloying of silver with copper. In our study, As concentrations in 30 Cu–Ag alloy samples from LB III–Iron Age I hoards, reach up to 7%, which is close to the maximum solubility of As in Cu (Fig. 4). The linear relationship between As and Cu for these items is a graphic expression of the ~7% limit (the best-fit line slope is 6%; Fig. 4), indicating that As (and in some cases also Sb) must have been added intentionally, rather than being a natural occurrence in the added copper (see more in Appendix B).

How As was added to copper remains an open question. In a yet unknown protocol, metallic arsenide ('speiss') was probably combined with copper (Thornton et al., 2009). Speiss was, indeed, available at least in the northern Levant and the Aegean during these periods; It had been unearthed in the Late Bronze Age copper workshop at Kamid el-Loz in Lebanon (Frisch et al., 1985: 146–148; Waldbaum, 1999:31), and in a Late Helladic IIIB (13th century BCE) workshop at Tiryns on mainland Greece (Kilian, 1983: 304; Waldbaum, 1999: 31), and was found in the form of ingots in Late Bronze Age Slovenia (12th– 9th centuries BCE, Paulin and Orel, 2003). Arsenical copper is well attested during this period in Egypt, where it was used for millennia, throughout the Old, Middle and New Kingdom periods, to produce mirrors and particular statuettes (D'Abbadie and Michel, 1972; Riederer, 1978; Schorsch, 1988; Masson-Berghoff et al., 2018). Skillful metal production in Egypt was closely controlled by the administration, as evident in the New Kingdom workshop at Qantir–Pi-Ramesses (Rehren and Pusch, 2009).

Another alloying technique, identified in one hoard only (BS 88866), was the formation of Cu–Ag alloys with different composition in the core (~40% Ag– 60% Cu) versus the exterior (80–88% Ag, 20–12% Cu). This may have been achieved by slow cooling (Thompson 2009: 605–606), or alternatively by soldering silver-copper sheets composed of eutectic compositions (72% Ag, 28% Cu) to silver-copper cores (40% Ag, 60% Cu). The soldering of the two is possible due to different melting points of the two alloys (Scott, 2011:29; 46–48).

Here we wish to underscore two points: (1) both alloying methods require sophisticated metallurgical skills, rarely used for silver. (2) there is a chronological development in the 'standardization' of silver debasement: The compositions of the LB III Ag–Cu items are uniform within each hoard. They contain large amounts of Cu (>20%), trace metal concentrations that are relatively constant (Figs. 3 and 4, B.1), and are found in ingot-form (see Table B.1). In contrast, Ag–Cu alloys dating to the Late Iron Age I vary widely in both Cu and trace metal concentrations, and many of the items consist of broken or re-melted jewelry (as indicated by the high Au concentrations). The precise process of this development cannot be traced with accuracy, since no hoard in the Levant can be decisively dated *between* these two periods, i.e., to the Early Iron Age I. The chronological development also manifests itself in the sources of copper (see below).

Can this be considered forgery? The phenomenon of deliberate addition of arsenic to 31 Ag–Cu alloys implies an attempt to conceal the alloying and thus deceive unwary recipients of the silver. Therefore, using the term forgery is to our minds warranted in this case. Future metallographic analysis may contribute to this question (Eliyahu-Behar et al., forthcoming). Based on chemical and isotopic analysis, forgery is indicated more clearly for the LB III, a period in which silver with copper cores and Ag–Cu–As alloys first originated, but is more difficult to evaluate for the Late Iron Age I hoards. During the later period copper was still deliberately added to the silver, from a new source (Faynan), however arsenic addition was not as common, and its concentrations are lower. Also, by the Late Iron Age I the phenomenon of alloying was already practiced for 150 years and was probably known and already accepted as norm. It is therefore possible that Ag–Cu alloying was initiated as a means of forgery in the LB III (perhaps by the ruling Egyptian elites), and gradually became a common practice during the Iron Age I, due to the lingering shortage of silver.

Finally, the transition to the Iron Age IIA (~950 BCE) marked a change in the form, quality and quantity of hoarded silver in the Southern Levant. Silver hoards from this period, sampled for this and earlier studies (BS 1029 in this study, and the Tel Dor, ʿAkko and ʿEin Hofez hoards, see OXALID, Thompson and Skaggs, 2013; Eshel et al., 2019), contained large quantities of unalloyed silver, in the form of 'cut ingots'. This, as mentioned, contrasts with earlier hoards, in which silver was hoarded in the form of sheets, rods and broken jewelry, "hacking" was practiced routinely, and hoards were smaller (Eshel et al., 2018). These changes single out the Iron Age IIA not only as a period of far flung trade in silver, but also as one with quality regulation. Hacking became a common method to verify the quality of hoarded silver, probably as a result of earlier Ag–Cu alloying.

4.2. Sources of silver to the Southern Levant during the LB III–Iron Age I (~1200–950 BCE)

Based only on the LI results of *unalloyed* silver in the present study, it is evident that a shift in ore sources providing silver to the Southern Levant occurred, from the Aegean in the LB III (the BS 88866 hoard), to the Taurus Mountains, Anatolia in the Iron Age IIA (the BS 1029 hoards; Fig. 6). This in accordance with results of previous studies (Thompson, 2009; Eshel et al., 2019; Yahalom-Mack et al., 2019), which suggested that silver in the Southern Levant during the LB II–III originated from the Aegean, and in the Iron Age IIA mainly from Anatolia, alongside Sardinia, and at a later stage mainly from Iberia (see also Martín Hernández, 2018 and results from the Tel Dor, ʿAkko and ʿEin Hofez hoards in OXALID).[1]

While the silver ore sources of the LB III and Iron Age IIA are reasonably clear, the sources of silver in the intermediate Late Iron Age I remain largely unknown, even though we enlarged significantly the number of sampled items (48 versus 15 previously). This is so since, as demonstrated, 41/48 are suspected of Cu addition. Notably, four unalloyed samples obtained here (Ashkelon_1, Ashkelon_3, Ashkelon_4, Ashkelon_9) plot beyond the isotopic range of Anatolian and Aegean ores. Of these, only one of the samples (Ashkelon_4) and another item from the same hoard in OXALID (2ASK001) have isotopic values consistent with lead ores of the Western Mediterranean (Sardinia or Iberia), in contrast to suggestions by Thompson and Skaggs (2013) and Wood et al. (2019) that significant quantities of Iron Age I silver originated from the West Mediterranean. As we previously suggested (Eshel et al., 2019), a fundamental problem with these studies is the disregard of the possible effects of high copper content in silver on the isotopic signature of the artefacts. For the remaining items, Sardinia/Iberia are less likely identified as a source based on the computational model that we applied (3.3.2.3 and Fig. 8). In addition, since Arabah copper was added to silver in the LB III, it is reasonable to assume that this probably occurred as long as there was no fresh supply of silver to the region. As we show, the Ashkelon hoard is very late in the Iron Age I (Appendix A), and the four samples from this hoard herald the first significant import of Western silver to the Levant during the Early Iron IIA.

Finally, Anatolia is represented as a silver source in the Late Iron Age I by one item only from Tell Keisan and corroborated by another item from the same hoard in OXALID (KSN_007).

4.3. Sources of copper

Based on our results we suggest a shift in the main origin of Pb-rich copper added to silver: from Timna in the LB III, to Faynan in the Late Iron Age I. This corresponds with the chronology of the operations of the south Levantine copper mines; Timna was operated by the Egyptians during the 13th–12th centuries BCE and then on a smaller scale by local societies throughout the Iron Age IIA, while Faynan became the main Cu mine after the Egyptian withdrawal in the 12th century BCE, and onwards (Rothenberg and Bachmann, 1988; 1990; Ben-Yosef et al., 2012; Avner, 2014; Levy et al., 2008; 2014; Yahalom-Mack and Segal, 2018). As for Pb-poor copper ore sources, we cannot know positively which ores these were. Cyprus was the first and foremost supplier of copper to the East Mediterranean in the Late Bronze Age, as shown by LIA of copper from the Uluburun shipwreck, Ugarit, the Carmel Coast and el-Amarna, Egypt (Gale, 1980; Kassianidou, 2008; 2013; Dardaillon, 2008; Stos-Gale and Gale, 2012; Yahalom-Mack et al., 2014; Rademakers et al., 2017; OXALID database). Other Pb-poor copper originated from Laurion in Greece, Anatolia and Sardinia (see references above). These metals may have been recycled during the Iron Age I.

Furthermore, there is a correlation between the source of copper and alloying techniques: The silver in most hoards (Megiddo H, Tell Keisan, Megiddo 2012; BS 1095) was debased by the addition of copper and the effect of the copper on the color of the alloy was masked by arsenic addition. The BS 88866 hoard is the only hoard which contains copper that could not have originated from the Arabah and is also the only hoard in which silver surfaces concealed copper cores.

5. Contextualizing the results

Between ~1250 and 1150 BCE, a series of calamities led to the disintegration of all major political and economic entities around the Mediterranean, including the Myceneans (Ward and Joukowsky, 1992; Broodbank, 2013: 458–472; Cline, 2014; Knapp and Manning, 2016). The years that followed were often denoted "The Dark Ages" and were described in terms of a global economic crisis and the near-cessation of cross-Mediterranean maritime trade (Sherratt and Sherratt, 1991; Cline, 2014). For the purposes of the current paper it is especially noteworthy that between ~1180 and 1150 BCE Egypt gradually lost its imperial holdings in the Levant, namely Canaan (Bietak 1993; Killebrew 2005: 81–83; Mazar 2011; Gilboa 2014; Bunimovitz 2018; Elayi 2018: 99–104; Koch 2018a, 2018b), but continued to operate the Timna copper mines until at least the days of Rameses the VI, ~1140 BCE (Rothenberg and Bachmann, 1988; 1990; Ben Yosef et al., 2012). Therefore, historically the LB III is the precise timeframe in which Egyptian elites still ruled Canaan, copper from Timna was abundantly available, while silver from the Aegean was scarce.

The drastic decline in metal trade was oftentimes considered as an important component in the Late Bronze Age collapse (Sherratt, 1994; Bell, 2006, 2009). However, while research focused mainly on copper/bronze and iron, little attention was accorded to silver (but see e.g., Sherratt, 2019). The results presented here emphasize the role of silver in the Late Bronze Age collapse and underscore the fact that the Bronze Age Collapse resulted in a shortage in silver, at least in the Levant. This was probably also true for Egypt as well as for other parts of the East Mediterranean, in which silver was used as currency in the 13th century BCE (for Egypt see Jurman, 2015; Muhs, 2016; for Babylonia, see Kleber, 2016). Although it has been suggested that the Laurion mines continued to produce and supply silver after the Mycenaean Bronze Age collapse (Gale and Stos-Gale, 1981; Mountjoy, 1995; Kelder 2016; Sherratt, 2019), there is no evidence that it was shipped to the East at this time.

To conclude, we postulate a connection between the cessation of silver supply to the Levant, a shortage in silver, and the consequent Ag–Cu alloying evident in the LB III–Iron I period, a phenomenon otherwise unattested in the Levant throughout the 2nd–1st millennia BCE. We date the beginning of this phenomenon, *grosso modo*, the year 1200 BCE (similarly to Thompson, 2009).

The shortage of silver lasted for a very long time (~1200–950 BCE), during which silver did not reach the Levant at all, or in very limited quantities, and Ag–Cu alloying and the reuse of existing silver were a response to its scarcity. During this timespan alloying practices and copper sources appear to develop and change:

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[1] Although there is lead from Sardinia in Cyprus during LC IIC–LC IIIA (Stos-Gale and Gale, 2012), we have no indications that contacts with Sardinia continued after the Late Bronze Age collapse and the destruction of several areas in Cyprus in the LC IIIA period (~1125 BCE; Voskos and Knapp, 2008). Also, there is no indication that the 2nd millennium lead production in Sardinia involved also silver production (see Valera et al., 2005; Eshel et al., 2019).

During the LBIII, when Egypt still ruled Canaan, most of the silver, which was used as currency, alongside other forms of wealth, was probably in the hands of the local Egypto-Canaanite elites (e.g., Higginbotham, 2000; Killebrew 2005; Koch 2018b). Significantly, the hoards of this sub-period were unearthed in major Egyptian administrative centers, of Beth Shean (Mazar, 2011) and Megiddo (Singer, 1989). The Egyptians operated the Timna copper mines, and had the knowledge needed to mix silver, copper and arsenic (see Appendix B). Skillful metal production in Egypt was closely controlled by the administration, as evident in the New Kingdom workshops at Qantir-Pi-Ramesse (Rehren and Pusch, 2009). Therefore, this organized, skillful and regulated initiative strongly points to an Egyptian initiative.

In the century following the Egyptians' withdrawal (Early Iron Age I; ~1150–1050 BCE), silver in the Levant continued to be scarce. Among 38 hoards from the Southern Levant, none can be securely dated to this period, faithfully mirroring the low ebb of inter-regional commerce in the Levant at that time (Gilboa et al., 2008; Gilboa et al., 2015; Gilboa, in press). In the Late Iron Age I Levant (~1050–950), significant changes were evident. Settlements reached an urban apex (e.g., Arie, 2012; Münger et al., 2011; Harrison, 2004; Gilboa, 2014), accompanied by significantly intensifying trade, driven mostly by private initiatives (Sherratt and Sherratt, 1991; Gilboa, 2015). Accelerating maritime trade, however, was still limited in its geographic extent. Abundant ceramics index extensive traffic mainly between Egypt, Cyprus and the Levantine coast, while only a handful of items in the Levant and the Aegean demonstrate sporadic connections beyond that (refs. in Gilboa et al., 2008: 143–145; Maeir et al., 2009; Mazar and Kourou, 2019; Kourou, 2019; Gilboa, in press).

This development is well attested in the silver hoards. Three (or four) hoards from this century, from different locales in Canaan, as opposed to one (or none) in the Early Iron Age I, truly reflect the economic recovery of the region. Notably, all of them were deposited in domestic contexts. This is in accordance with the significant shift from palatial to private economy throughout the LB/Iron Age transition (e.g., Sherratt and Sherratt, 1991).

Prosperity notwithstanding, silver was still in short supply in the Levant, thus the continuous use of silver-copper alloys, now with copper from Faynan, as well as recycling of older silver. In contrast to the LB III, widely varied compositions of the alloys and lower Cu and As content, negate the occurrence of organized and standardized alloying practices. If, indeed, the Egyptian administration was behind the LB III silver debasement, it appears that standardized forgery schemes (and knowledge) disappeared along with it. What persisted is the notion that silver alloyed with copper can be used as a means of payment. Namely, the use of alloys may have evolved from forgery to an agreed convention.

Finally, two samples in the hoard of Phoenician Tell Keisan, and four from the Philistine Ashkelon hoard represent the beginning of the revival of long-distance trade in silver from Anatolia (Taurus) and the West Mediterranean (Sardinia/Iberia) to the Southern Levant, which is well-attested from the mid-10th century BCE (Early Iron Age IIA). The latter has been discussed in Eshel et al. (2019), and is substantiated by the BS 1029 hoards in this study, which also date to the Iron Age II. This new endeavor has been attributed to the Phoenicians (Eshel et al., 2019), and suggests that a change in ore sources occurred, from Laurion in the LB II–III to Anatolia and the West Mediterranean in the Iron Age IIA, with a long shortage period during the Iron Age I. During the Iron Age IIA, the hoards were larger, the silver ingots themselves were larger (e.g., Fig. 2f) and most importantly, the silver was pure, all signaling a previously unrecognized large-scale import of silver.

Although Thompson and Skaggs 2013 and Wood et al., (2019) suggested that silver from Sardinia and/or Iberia reached the Levant already in the 11th century BCE, possibly even earlier, results of the current study show that this can be demonstrated for the Ashkelon hoard only, which is currently dated to the very end of the Late Iron Age I, yet awaits final publication (Appendix A, D. Master, personal communication). For other hoards from this period, for the time being, this cannot be demonstrated analytically. The contribution of copper from Faynan is able to explain most of the isotopic compositions of the Cu–Ag alloys that were previously interpreted as demonstrating silver originating from the West.

Declaration of competing interest

None.

Acknowledgments

We thank Miki Saban, Alegre Savriago and Fawzi Ibrahim from the Israel Antiquities Authority for enabling the sampling and photography of the Ashkelon, Beth Shean (1095, 1029), Tell Keisan and Megiddo (2012) Hoards. We are also grateful to the following individuals who kindly allowed us to sample and photograph hoards and shared relevant knowledge regarding their contexts: Amihai Mazar, The Hebrew University of Jerusalem (Beth Shean 88866), Eran Arie, the Israel Museum and Israel Finkelstein, Tel Aviv University (Megiddo Area H), Jean-Baptiste Humbert from the École Biblique et Archéologique Française in Jerusalem (Tell Keisan), and Daniel Master, Wheaton College (Ashkelon). We are deeply thankful to Thilo Rehren from the Cyprus Institute, Benjamin Sass and Oren Tal from Tel Aviv University, William Hafford of the Penn Museum, Martin Odler, Charles University, Haim Gitler from the Israel Museum and Julian Zurbach from the Ecole Normale Supérieure for sharing with us their knowledge in various subjects. Many thanks to Svetlana Matskevich who skillfully produced the graphics. We deeply thank Adi Ticher and Renana Oz-Rokach for careful and dedicated work in the laboratory. Finally, we wish to thank Yehuda Enzel from The Hebrew University of Jerusalem, for referring us to the opening phrase, cited from Ezekiel.

Appendix A

Contents, contexts and chronology of silver hoards from the Southern Levant discussed in this paper. Hoards are presented in proposed chronological order.

Table A.1
Comparison of the relative chronology terminologies used by the main sites discussed in this paper

Megiddo (Toffolo et al., 2014; the terminology used here)	Beth Shean (Mazar and Kourou, 2019)	Tell Keisan (Gilboa et al., 2018: Chart 1; Phoenician terminology)	Ashkelon (Master, forthcoming, table 6.1)	Compromising Absolute Chronology (a combination of the mentioned publications)
Late Bronze Age III (LB III)	Iron IA	LB| Ir	Iron I - Monochrome	~1200–1150 BCE
Early Iron Age I	Iron IB (ends ~980)	Ir1a	Iron I - Bichrome	~1150–1050 BCE
Late Iron Age I		Ir1b		~1050–950 BCE

(continued on next page)

Table A.1 (*continued*)

Megiddo (Toffolo et al., 2014; the terminology used here)	Beth Shean (Mazar and Kourou, 2019)	Tell Keisan (Gilboa et al., 2018: Chart 1; Phoenician terminology)	Ashkelon (Master, forthcoming, table 6.1)	Compromising Absolute Chronology (a combination of the mentioned publications)
Early Iron Age IIA	Early Iron Age IIA (ends ~920)	Ir1|2 transition	Iron II	~950–900 BCE
Late Iron Age IIA	Late Iron Age IIA (ends ~830)	Ir2a		~900–815 BCE

Table A.2
Relative terminology, absolute chronology, context, content and sampled items from LB III–Iron Age hoards, as specified below

sub period (relative terminology)	absolute chronology	hoard	context	weight	ceramic vessel	bundles*	metals	content**	of samples in this study	OXALID
Late Bronze Age III	~1200–1150 BCE	Beth Shean 88866	Egyptian garrison, 20th dynasty	157 g	X	3	silver, copper	broken jewelry, rods, sheets, cut ingots	10	5
		Megiddo H	near palace	98 g	V	1	silver, copper	rods, electrum and gold jewelry, carnelian and metallic beads	13	–
Early/Late Iron Age I	~1150–950 BCE	Beth Shean 1095	large building	1.3 kg	X	1	silver, copper	cut ingots and a stone weight	6	–
Late Iron Age I	~1050–950 BCE	Ashkelon	domestic/ industrial	100 g	X	2	silver, copper	sheets, broken jewelry, 'cut ingots'	11	7
		Megiddo 2012	domestic	425 g	X	3	silver, copper	sheets, broken jewelry, 'cut ingots'	11	–
		Megiddo 5213	domestic?	–	X	1	silver, copper	Unknown	–	–
		Tell Keisan	domestic	354 g	V	~4	silver, copper	sheets, broken jewelry, 'cut ingots'	19	8
Iron Age IIA	~950–800 BCE	Beth Shean 1029a	temple/ marketplace	2 kg	V	X	silver	cut ingots	15	–
		Beth Shean 1029 b	temple/ marketplace	1.9 kg	V	X	silver	cut ingots		
Sum									**85**	**20**

* V = yes, X = no
**descriptions after Eshel et al. (2018).

1. Beth Shean 88866 (BS 88866)

Beth Shean was one of the major Egyptian administrative centers in Canaan. Three bundles were found in Building SD, Locus 88866, Stratum S-4, on top of a basalt-slab floor coated with white lime. Stratum S-4 of the Hebrew University (HU) excavations is securely dated to the first half of the 12th century (Level Lower VI of the University Museum Expedition, University of Pennsylvania [UME]); Mazar, 2011n and Mazar, 2009: 13, 129; Thompson (2009). In terms of the relative chronology employed in this paper, this hoard dates to the LB III. The bundles were left on the floor and buried under the collapse of the abandoned building (Mazar, 2011n and Mazar, 2009: 123–124).[2]

The three bundles weighed 56.2, 34.8, and 66.3 g each, and contained broken jewelry, rods, sheets and cut ingots, a slightly flaring mushroom-head net-pattern toggle pin, and a signet ring inscribed with imitations of hieroglyphic script (Fig. 2A in main text; Thompson, 2009; Gilboa et al., 2008). Mushroom-head pins are common in Anatolia (Egeli, 1995), and appear in the Southern Levant during several periods (Henschel-Simon, 1938; Ilan, 1992). The ring has parallels from late 13th century contexts at Tel Nami, Tell el-Farah South and Megiddo that bear Hittite names and originate from either Syria or Anatolia (Singer, 1993; 2007). The ring from Beth Shean, however, is illegible (Thompson, 2009: 607), and according to Golani (2009: 631, note 8) might be a local/Phoenician imitation.

One of the hacked ingots was identified as having a silver-enriched surface and a copper-rich core.[3] This has been explained as a deliberate deception, produced by intentional slow cooling of the alloy, creating silver enrichment on the surface (Thompson, 2009).

2. Megiddo Area H (Megiddo H)

Megiddo was one of the most important Canaanite cities located in the Jezreel Valley. The Megiddo hoard, excavated by the Tel Aviv University expedition, consisted of a single bundle, originally wrapped in textile, found alongside an assemblage of electrum, carnelian and silver beads that formed a necklace, additional electrum jewelry, including unique earrings and a signet ring. The 98-g bundle contained mainly silver-copper alloy cut rods and hacked ingots (Fig. 2B in main text; Arie et al., 2019).

The hoard was placed inside a ceramic strainer spout jug within a bowl and was covered by another bowl. It was found on a paved floor, in the northeastern corner of a rather small, inner courtyard in Area H, Level H-11. Area H is located near the Canaanite Palace 2041 associated with Stratum VIIA (Arie et al., 2019). Level H-11 was originally assigned by the Tel Aviv University excavators to the University of Chicago's Stratum VIB, yet based on its proximity to Palace 2041 and a large conflagration which destroyed both H-11 and the palace, it was reassigned to Chicago's Stratum VIIA and

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[2] Thompson (2009) claimed this room was a silversmith workshop, yet presented no evidence for this assertion.

[3] Three additional cut ingots of Ag–Cu alloy with a copper-rich core were identified in this research (see main text).

associated with the palace (Frisch et al., 1985). The end of Stratum VIIA, initially dated by the Tel Aviv University expedition to the 12th century BCE, was re-dated by them to the first half of the 11th century BCE (Early Iron Age I in relative chronology), post-dating the Egyptian presence in Megiddo. This was based on ceramics, including Philistine Bichrome vessels, and on extensive radiometric dating of Level H-11 (Toffolo et al., 2014; Frisch et al., 1985). Therefore, the destruction of Level H-11 and the nearby Palace 2041 were dated ~1070 BCE, and the hoard was connected by the excavators to this event (Frisch et al., 1985; Arie et al., 2019).

Here we follow the latest stratigraphic reconstruction and chronology suggested by the excavators. We also accept their suggestion that some of the objects in the hoard, designed in unique Egyptian styles and compositions, may have been heirlooms that "echo the days of Egyptian rule in Megiddo" (Arie et al., 2019: 98). We further claim that this is true for the entire hoard, as evident by the lamp-and-bowl style hoarding (although in this case a strainer spout jug was used instead of an oil lamp), which also has an Egyptian origin (Bunimovitz and Zimhoni, 1993; Hall, 2016). Most significantly, the textile in which the bundle was wrapped produced ^{14}C dates that are older than the rest of the stratum (calibrated dates: 1446–1296 BCE (68.2%) ±1σ; 1513–1209 BCE (95.0%), ±2σ; Toffolo et al., 2014: 228). This is a rare case in which the date of the hoard can be distinguished from its final deposition, which is post-Egyptian (see above). Therefore, the formation of the hoard is attributed to the days of local level H-12, Chicago's Stratum VIIA, the late 12th and very early 11th centuries BCE (Frisch et al., 1985); it may in fact be even earlier.

3. Beth Shean 1095 (BS 1095)

The hoard, excavated by the University of Pennsylvania Museum in the 1920's, was wrapped in cloth, and weighed ~1.3 kg (Rowe, 1940: 19). The hoard contained ingots, sheets, rods, broken jewelry, a gold armlet and a grey ~43 g sandstone weight (Fig. 2C in main text; Rowe, 1940: 19; Heymans, 2018: 285). It was found under the south wall of Room 1095, an inner room in Building 1093–99, directly north of the so-called Temple of Seti I (Rowe, 1940: 19; Pl. V). Since silver hoards seldom served as foundation deposits (Vargyas, 2000; Eshel et al., 2018), the location of the hoard under an internal wall of the structure suggests that the wall might have been a later addition to the structure, perhaps intended to conceal the hoard. The hoard should therefore be dated to the later phases of the usage of the building.

Room 1095 and Structure 1093–99 were attributed by Rowe to the late level of the Temple of Seti I, and associated by him with the town's Late Level VI, immediately postdating the Egyptian 20th Dynasty presence at the site (Rowe, 1940: 19; Pl. IV-V). Frances James, who re-published and reinterpreted the UME excavations, was indecisive as to the association of Structure 1093–99, debating between the two phases of Level VI and Lower Level V (see below and James, 1966: 21–22, 27, Figs. 74, 76.2, 77). She noted that the level of the building was 1–3 m higher than other structures related to Level VI, yet commented that this might be due to its location near the summit of the tell. James defined the ceramic assemblage from the building as mixed, containing types typical both of Level VI and Lower Level V (James, 1966: 27, Fig. 2). Finally, in the town plan, James assigned the building to Late Level VI (the latest phase of Level VI, James, 1966: Fig. 77), in agreement with Rowe.

The stratigraphy was revisited by Amihai Mazar, who suggested that the building might be a continuation of Building SL of the Hebrew University excavations, thus assigning it to Lower Level VI, i.e., to the last phase of Egyptian presence at Beth Shean (1st half of the 12th century BCE, Mazar, 1993: 208, Fig. 4; Mazar, 2011n and Mazar, 2009: 7, Fig. 1.5; 152). Panitz-Cohen and Mazar, being aware of the significant difference in levels, described the building as "enigmatic" (Mazar, 2011n and Mazar, 2009: 152).

The only indicative ceramics from the building are: a rounded bowl (James, 1966: Fig. 2.8) typical of the LB IIB–III (Mullins and Yannai, 2019: 154), although such a simple shape could also be later; a cooking pot (James, 1966: Fig 2.2) typical of the Iron Age I (Mazar, 2011: 12–13, pl. 1.1.10–11); and a jug with a strainer spout and purple-painted decorations (James, 1966: Fig. 2.4) typical of the 11th century, Late Iron Age I (Mazar, 2011: 16; pl. 1.1.22:1–6). The ceramics are the best indicators for the date of the building, or at least its final use, suggesting a date within the Iron Age I.

In addition, structure 1093–99 was, in fact, found immediately below the so-called Northern Temple of Rameses the III, constructed according to James in Level Lower V, and therefore must have preceded it (on the dating of the Northern Temple see more below, regarding the Beth Shean hoards 1029a and 1029 b). We thus conclude that the level of the structure, its stratigraphic position and its pottery, all imply that both the structure and hoard should be dated post-Level Lower VI (the latest Egyptian presence), yet earlier than Lower Level V. Stratigraphically, this corresponds to Late Level VI and in terms of the relative chronology I employ here, the hoard dates either to the Early or Late Iron I, or Iron Age IB in the terminology employed at Beth Shean (see Table A.1), ~1150–950 BCE.

4. Ashkelon

Philistine Ashkelon is situated on the southern coast of the Southern Levant. The hoard consists of two bundles, weighing 44.79 and 55.05 g before cleaning. They contain a variety of cut and broken objects, including ingots and ornamental items of different types (Figure 2.3.1; Thompson, 2009; Gitler and Tal, 2019: Fig. 1). It was discovered on a stone pavement in Room 530 (a later subdivision of Room 667) just south of a typical Philistine keyhole-shaped hearth (Stager, Schloen and Master, 2008: 267–271, Fig. 15.36; the later sub-phase is not presented on the plan). The bundles were found under a deposit of striated grey ash, thought to be the result of the use of the hearth over time (D. Master, personal communication). We can therefore exclude the suggestion that the hoard was cached beneath a later floor (Heymans, 2018) and it can be safely attributed to Phase 18a of Grid 38 (Stager, Schloen and Master, 2008: 270, Fig. 15.42; D. Master, personal communication). Phase 18 is the second phase yielding Philistine Bichrome ware and is assigned by the excavators to Ashkelon's Period XV ("late Bichrome"/Iron I), which is the last of three sub-phases of the Iron Age I at the site (Stager, Schloen and Master, 2008: 217). In the terminology we employ here, it can currently be assigned to Late Iron Age I, awaiting final publication (D. Master, personal communication).

5. Megiddo Area AA, Room 2012 (Megiddo 2012)

A hoard of hacksilber consisting of three bundles was found in Area AA excavated by the University of Chicago (Loud, 1948: Pl. 229: 7–9; Harrison, 2004: 17, 78, Fig. 125, pl. 29: 9–11). The bundles were not deposited inside a vessel. The total weight of the hoard is 425 g (Heymans, 2018: 291), and consists of an assortment of silver ingots, wire, foil decorated with rosettes or cross-hatching, as well as whole and broken jewelry (Loud, 1948: Pl. 229: 7–9). The exact find-spot of the hoard is not described in the publication. It was generally associated by the excavators with Room 2012 (Squares K7/K8 in Loud, 1948: Fig. 386), located in a domestic area immediately to the west of Building 2072) (Loud, 1948: Pl. 229: 7–9, Fig. 386). The latter is generally considered the palace of the Stratum VIA city. According to Loud's 1935-6 diary, page 25, the hoard was deposited beneath the Stratum VIA floor (Heymans, 2018), dated to the Late Iron Age I of Canaanite Megiddo. The stratum was destroyed by a heavy conflagration (the agent of which is debated; e.g., Frisch et al., 1985). After the bundles were opened and cleaned, their contents were combined and distributed between the Oriental Institute of the University of Chicago and Jerusalem's Rockefeller Museum (Heymans, 2018).

6. Tell Keisan

The Phoenician site of Tell Keisan is situated not far from the northern coast of the Southern Levant, on the ʻAkko Plain (Briend and Humbert, 1980). The hoard, found inside a Phoenician Bichrome jug, was excavated by the R. de Vaux, J. Pringnaud, J. Briend, and J.-B. Humbert of the École Biblique et Archéologique Française in Jerusalem. It contained 354 g of silver, wrapped in four or more bundles, originally stamped by bullae. The jug was found in the courtyard of a domestic complex, in Stratum 9a, Area B, L635, under or inside a collapsed wall (Briend and Humbert, 1980: 198–99). Based on stratigraphy, ceramics, radiocarbon dating of the bundles, and typology of the bullae, the hoard should be dated to the Late Iron Age I in relative terms (Phoenician Ir1b: Gilboa et al., 2008), and in absolute terms – ~1050–950 BCE (detailed discussion with references in Eshel et al., 2018).

7. Beth Shean 1029 (a+b), (BS 1029)

Two hoards were found in the so-called Southern Temple of Rameses III, which is one of two public structures of Level Lower V (known as the Northern and Southern Temples), excavated by the University of Pennsylvania Museum expedition in the early 20th century. Both hoards were large, each containing approximately 2 kg of silver, gold, and a few ingots of undetermined metal coated by gold foil (Rowe, 1940: 26, pls. XXIX, LXVIA:12, 13, 32–34; Vargyas, 2000). The hoards were placed to the east of the two middle columns of the central aisles of the Southern Temple, one in the northern (A) and the other in the southern (B) isle (James, 1966: Fig. 73). The hoards were described as "foundation deposits" (Rowe, 1940: 26). This interpretation was contested by Peter Vargyas (2007), who claimed the hoards were carefully positioned near the column bases for easy retrieval, an explanation that I find convincing (Eshel et al., 2018: 215, 220).

James accepted Rowe's observation that the Southern and Northern Temples of Level V are contemporary and comprise a single complex (James, 1966: Fig. 73–75). She, nevertheless, divided Rowe's Level V into two sub-phases and attributed the establishment of the temples to Lower Level V, namely Iron Age IIA (James, 1966: 33–34, 59–60).

The northern rooms of the Southern Temple underwent reconstruction throughout the Iron Age, and two phases were distinguished. The later phase was assigned by Rowe to Level IV and reassigned by James to Upper Level V (Iron Age IIB, Rowe, 1940: pl. III, X; James, 1966: 141–143, 146–147). The extent of the rebuilding is not fully known (James, 1966: 141–143). It has been claimed that the pillars were not part of the original building, but added later (Mullins, 2012: 145), although Rowe (1940: 25) and James (1966: 142) claim the opposite. A third scenario by Mazar proposed that the temples were initially constructed in Late Level VI (Iron IB in Beth Shean, 11th century BCE according to Mazar, see above), based on the presence of numerous cultic objects in the Southern Temple. Mazar dated a second reconstruction phase of the building to Lower Level V (Iron IIA, Mazar, 1993: 221–223, 2006: 34–35; Mazar, 2011n and Mazar, 2009: 10–11, 27–28).

We revisited the ceramic assemblage of the Southern Temple. It is, in fact, mixed and includes ceramics datable to both the Late Bronze and Early Iron Ages, as well as one Cypriot Black-on-Red sherd specifically datable to the Late Iron Age IIA (James, 1966: Fig. 6: 14). The earlier ceramics might be explained by the fact that in some areas, the excavators sometimes dug below the floors (see James, 1966: 141–143). Regardless, since the Northern Temple was built over the debris of Late Level VI, the temple complex must post-date this level, i.e. post-date the Late Iron Age I. As to Mazar's claim regarding the "early" cultic vessels–meaning that they indicate an earlier, 11th century BCE date for the establishment of the Northern and Southern Temples–the reuse of old relics of symbolic significance is known at the Beth Shean temple complex, best represented by the positioning of monuments from earlier levels in front of the Northern Temple: a statue of Ramesses III and stelae of Seti I and Ramesses II (Mazar, 2011n and Mazar, 2009: 10). Therefore, the cultic stands may also have been used secondarily, and do not necessarily rule out James's chronology for the temples. Moreover, continuity of ceramics and cultic Canaanite practices and paraphernalia into Iron Age IIA was noted as a hallmark at nearby Tel Rehov (Mazar, 2011) and Tell el-Hammah (Cline, 2014) and seems to have been a characteristic of the Beth Shean Valley. It is therefore possible that the Iron I cultic stands were re-used or produced during the Iron Age IIA. Based on the single Black-on-Red sherd, we cannot exclude the Late Iron IIA as a possible dating for this hoard. Therefore, the establishment of the temple complex, and the terminus post quem for the hoards should be generally attributed the Iron IIA (~950–800 BCE). Because of this dating, the hoards are beyond the chronological scope of the Iron Age I, although they are customarily associated with this period (e.g., Eshel et al., 2018; Heymans, 2018). As their analysis adds a long-term perspective and corroborates the main conclusions of the Iron Age I discussion, they are discussed in this paper alongside earlier Iron Age I hoards (see main text).

Iron Age Hoards Not Sampled

Two additional hoards dating to the Iron Age I were not sampled in this study: A hoard from Megiddo L 5213 (Stratum VIA, Late Iron Age I; Loud, 1948: 187, Pl. 228:4–6), which is stored in the Oriental Institute in Chicago, was unavailable to us; and a hoard from a cave in Wadi el-Makkuk in the Judean Desert (Sass, 2002), which lacks a datable context and was only generally dated to Iron Age I based on the typology of the hoarded jewelry.

Appendix B

Chemical and Isotopic Results and Definitions of Compositional Groups

The chemical results are presented in Table B.1.

1. Introduction

Silver was produced in antiquity from argentiferous galena (silver rich lead-sulfide ores) and rarely from native silver ores (Meyers, 2003; Cline, 2014; Pernicka, 2014). The production process included two steps, in which a lead-rich ore was first smelted and lead-silver alloy was formed and

Table B.1

Chemical composition (in ppm, Cu in wt.%) and Pb-isotopic ratios (including uncertainties, 1σ) of the analyzed silver items. Empty cells indicate values below detection limit. Iridium was analyzed but not detected. Type descriptions after Eshel et al. (2018).

Period	hoard	bundle	sample ID	type	Cu wt%	Pb	Au	Bi	Fe	Co	Ni	Zn	As	Sn	Sb	$^{206}Pb/^{204}Pb$ ± 1σ	$^{207}Pb/^{204}Pb$ ± 1σ	$^{208}Pb/^{204}Pb$ ± 1σ
LB III	**Megiddo H**	1	Megiddo H_13	rod	61	1253		992	32	3	381	53	43067	16	1021	18.298 ± 0.001	15.651 ± 0.001	38.408 ± 0.002
		1	Megiddo H_14	cut ingot	74	2100	4072	6	31	1	338		38242		947	18.183 ± 0.002	15.640 ± 0.002	38.279 ± 0.005
		1	Megiddo H_15	rod	82	15472	3942	22	44	14	869		45300		1195	18.778 ± 0.002	15.680 ± 0.002	38.834 ± 0.004
		1	Megiddo H_21	rod	71	1142		164	65	3	456	17	37622	8	1342	18.309 ± 0.001	15.650 ± 0.001	38.416 ± 0.002
		1	Megiddo H_22	rod	68	867		164	21		280	29	37596	17	2051	18.205 ± 0.001	15.651 ± 0.001	38.313 ± 0.002
		1	Megiddo H_24	rod	71	1934		121	126	8	471	15	37242	12	1919	18.261 ± 0.000	15.648 ± 0.001	38.364 ± 0.001
		1	Megiddo H_25	rod	67	1051		43	286	3	420	14	45328	5	1362	18.310 ± 0.001	15.647 ± 0.001	38.411 ± 0.003
		1	Megiddo H_26	rod	61	10331		44	64	3	595	31	35075	16	1544	18.775 ± 0.001	15.684 ± 0.001	38.841 ± 0.002
		1	Megiddo H_27	rod	23	1083		29	37	41	345	22	150	7	100	18.305 ± 0.002	15.692 ± 0.001	38.432 ± 0.003
		1	Megiddo H_28	rod	76	2480		44	207	5	371	37	36978	8	1006	18.039 ± 0.001	15.626 ± 0.001	38.136 ± 0.003
		1	Megiddo H_29	square ingot	67	2090		31	67	14	384	17	31545	3	1614	18.241 ± 0.001	15.648 ± 0.000	38.347 ± 0.002
		1	Megiddo H_30	droplet	41	2350		175	230	5	382	47	14327	41	1818	18.347 ± 0.001	15.656 ± 0.001	38.436 ± 0.002
		1	Megiddo H_33	sheet	52	13256		89	120	3	258	44	33256	8	2488	18.380 ± 0.001	15.658 ± 0.002	38.472 ± 0.004
	Beth Shean 88866	1	BS 88866_2	rod	3	1572	203	1038	176		8	4	4	14	1	18.857 ± 0.001	15.689 ± 0.001	38.957 ± 0.005
		1	BS 88866_4	earring	4	1204	23983	636	210	1	10	3	23	64	2	18.861 ± 0.001	15.684 ± 0.001	38.964 ± 0.003
		1	BS 88866_6	braclet	55	620	2555	445	421	7	205	5	1901	9	99	18.679 ± 0.001	15.679 ± 0.001	38.754 ± 0.003
		1	BS 88866_7	toggle pin	2	653	179	415	124		1	4	20	5	2	18.815 ± 0.001	15.682 ± 0.001	38.854 ± 0.003
		2	BS 88866_13	rod	3	1511	179	629	158	1	10	3	5	16	2	18.857 ± 0.001	15.686 ± 0.000	38.952 ± 0.001
		2	BS 88866_15	rod	4	1584	208	856	72		12	3	5	15	2	18.861 ± 0.001	15.691 ± 0.001	38.968 ± 0.003
		2	BS 88866_19	earring	4	1798	156	3135	393	1	6	4	10	4	2	18.733 ± 0.001	15.678 ± 0.002	38.869 ± 0.006
		3	BS 88866_24_coating	cut ingot	20	1277	125	1102	59	2	42	11	107	196	41	18.686 ± 0.002	15.677 ± 0.001	38.753 ± 0.004
		3	BS 88866_24_core	cut ingot	59	804	268	445	765	12	202	13	1471	77	58	18.679 ± 0.001	15.679 ± 0.001	38.751 ± 0.003
		3	BS 88866_25_core	cut ingot	57	663	37	163	540	15	223	8	1321	124	47	18.686 ± 0.002	15.677 ± 0.001	38.759 ± 0.004
		3	BS 88866_25_coating	cut ingot	31	946	95	469	129	3	316	48	334	130	50	18.698 ± 0.002	15.678 ± 0.002	38.770 ± 0.008
		3	BS 88866_27_coating	cut ingot	12	1584	269	918	157	2	58	23	184	358	52	18.683 ± 0.002	15.668 ± 0.002	38.727 ± 0.004
		3	BS 88866_27_core	cut ingot	57	656	44	117	145	12	218	6	1450	48	46	18.677 ± 0.002	15.678 ± 0.002	38.747 ± 0.006

(*continued on next page*)

Table B.1 (*continued*)

Period	hoard	bundle	sample ID	type	Cu wt%	Pb	Au	Bi	Fe	Co	Ni	Zn	As	Sn	Sb	^{206}Pb/^{204}Pb ± 1σ	^{207}Pb/^{204}Pb ± 1σ	^{208}Pb/^{204}Pb ± 1σ
Late Iron Age I	**Beth Shean 1095**		BS 1095_1	cut ingot	31	1288	12	95	20		219	1	26144		408	18.725 ± 0.002	15.690 ± 0.002	38.811 ± 0.005
			BS 1095_2	cut ingot	30	2464	17	115	38	6	836	6	15839		453	18.577 ± 0.002	15.663 ± 0.002	38.527 ± 0.002
			BS 1095_3	token	1	53	18	41	25		1	1	19			18.654 ± 0.065	15.633 ± 0.045	38.628 ± 0.120
			BS 1095_4	token	31	4259	39	15	3	13	299	9	7340		95	18.437 ± 0.042	15.708 ± 0.034	38.573 ± 0.092
			BS 1095_5	cut ingot	33	1289	40	10			266	12	6687		104			
			BS 1095_6	cut ingot	37	2219	51	46	174	6	626	1	15057		118	18.556 ± 0.011	15.670 ± 0.009	38.144 ± 0.022
	Tell Keisan	2	Keisan 2_15	token	28	640		159	1131	302	19876	844	1391	64	54	18.397 ± 0.001	15.660 ± 0.001	38.486 ± 0.004
		2	Keisan 2_2	cut ingot	27	2111	232	127	234	11	245	3	18760		347	18.341 ± 0.001	15.653 ± 0.001	38.315 ± 0.003
		2	Keisan 2_25	rod	12	946			4	14	468	3	248		12	18.488 ± 0.003	15.660 ± 0.003	38.455 ± 0.006
		2	Keisan 2_4	cut ingot	21	1163	154	133	14	9	108	6	9325		136	18.575 ± 0.001	15.666 ± 0.002	38.516 ± 0.004
		2	Keisan 2_40	cut ingot	19	1609		1	17	14	239	14	147		27	18.786 ± 0.002	15.678 ± 0.001	38.719 ± 0.004
		2	Keisan 2_46	cut ingot	21	4162	16	21	32	3	149	4	15743		347	18.539 ± 0.001	15.665 ± 0.001	38.477 ± 0.004
		2	Keisan 2_49	cut ingot	15	10645			15		78	6	3442		120	18.386 ± 0.001	15.686 ± 0.001	38.384 ± 0.004
		2	Keisan 2_7	cut ingot	28	3952	11	6	20	3	221	6	8890		31	18.552 ± 0.002	15.661 ± 0.002	38.128 ± 0.008
		2	Keisan 2_8	sheet	30	1441	10	56	60		287	4	18414		441	18.483 ± 0.002	15.665 ± 0.002	38.458 ± 0.005
		6	Keisan 6_17	cut ingot	6	2310	35	17	49		6	528	29		27	18.399 ± 0.001	15.688 ± 0.001	38.406 ± 0.003
		6	Keisan 6_18	token	35	14857	4	10	2	8	402	331	7949		4	18.912 ± 0.003	15.684 ± 0.002	38.974 ± 0.006
		6	Keisan 6_26	rod	31	2446	129	4	19	5	260	10108	8619		438	18.351 ± 0.001	15.672 ± 0.001	38.339 ± 0.002
		6	Keisan 6_27	rod	22	4121		49	20		91	51	1051		102	18.262 ± 0.002	15.667 ± 0.001	38.226 ± 0.004
		6	Keisan 6_28	wire (jewerly)	15	401			50	1114	9888	5	36		6	18.501 ± 0.001	15.677 ± 0.001	38.470 ± 0.003
		6	Keisan 6_55	rod	41	3841	35	41	44		572	16	19532		105	18.596 ± 0.002	15.670 ± 0.002	38.535 ± 0.005
		8	Keisan 8_29	sheet	22	3617	680	19	451		47	41	13410		249	18.198 ± 0.002	15.661 ± 0.002	38.324 ± 0.005
		8	Keisan 8_33	earring	15	2156	3317	13	7		114	1315	729		34	18.312 ± 0.001	15.654 ± 0.001	38.279 ± 0.002
		8	Keisan 8_37	sheet	18	1589	2581		3	3	375	3	1460		20	18.441 ± 0.002	15.661 ± 0.001	38.417 ± 0.003
		8	Keisan 8_4	cut ingot	6	11300	1732	9	4		8	720	343		3	18.439 ± 0.002	15.659 ± 0.001	38.416 ± 0.003
		8	Keisan 8_59	token	12	5398	5584	31	14		64	10	330		18	18.837 ± 0.001	15.679 ± 0.001	38.787 ± 0.003

(*continued on next page*)

Table B.1 (*continued*)

Period	hoard	bundle	sample ID	type	Cu wt%	Pb	Au	Bi	Fe	Co	Ni	Zn	As	Sn	Sb	$^{206}Pb/^{204}Pb$ ± 1σ	$^{207}Pb/^{204}Pb$ ± 1σ	$^{208}Pb/^{204}Pb$ ± 1σ
	Megiddo2012		Megiddo 2012_1	cut ingot	26	2762	27	6		13	637	11	7171		39	18.512 ± 0.002	15.676 ± 0.002	38.602 ± 0.004
			Megiddo 2012_2	cut ingot	9	1062	5712	273	34		45	822	43	108	16	18.552 ± 0.002	15.664 ± 0.002	38.534 ± 0.004
			Megiddo 2012_3	cut ingot	11	1023	22	18	45	1	196	203	70		7	18.718 ± 0.003	15.684 ± 0.003	38.801 ± 0.006
			Megiddo 2012_4	cut ingot	36	2068	34	1346	35	13	574	1216	361	5208	157	18.639 ± 0.001	15.670 ± 0.001	38.747 ± 0.002
			Megiddo 2012_5	rod	6	1065	65	428	5		29	27			2	18.768 ± 0.003	15.677 ± 0.002	38.840 ± 0.005
			Megiddo 2012_6	cut ingot	13	1659	5343	49	2		111	101	2838		24	18.437 ± 0.002	15.653 ± 0.002	38.418 ± 0.005
			Megiddo 2012_7	cut ingot	9	1019	3281	10	0	1	101	3	4			18.641 ± 0.001	15.669 ± 0.001	38.583 ± 0.002
			Megiddo 2012_8	cut ingot	46	325	3627	9	6		489	2	23772		83	18.717 ± 0.001	15.664 ± 0.001	38.664 ± 0.003
			Megiddo 2012_9	cut ingot	8	1122	124	31			37	1	14			18.685 ± 0.001	15.679 ± 0.001	38.757 ± 0.004
			Megiddo 2012_10	cut ingot	34	1840	919	8	2		393	1	26751		410	18.520 ± 0.001	15.665 ± 0.001	38.518 ± 0.003
			Megiddo 2012_11	cut ingot	55	1334	56	95	1749	7	342		29977	37	1879	18.438 ± 0.007	15.668 ± 0.005	38.537 ± 0.015
	Ashkelon		Ashkelon_1	cut ingot	4	1692	1878	213	82		76	7	308		37	18.464 ± 0.002	15.668 ± 0.002	38.522 ± 0.004
			Ashkelon_2	cut ingot	8	613	116	587	96		6	89	12		7	18.706 ± 0.001	15.684 ± 0.001	38.796 ± 0.002
			Ashkelon_3	cut ingot	4	1600	190	220	14	6	55	10	355	125	148	18.518 ± 0.001	15.661 ± 0.001	38.514 ± 0.003
			Ashkelon_4		3	821	6661	13	44		6	4	428		60	18.227 ± 0.002	15.649 ± 0.002	38.226 ± 0.004
			Ashkelon_5	cut ingot	9	1525	26	68	2		32	42	10			18.487 ± 0.001	15.688 ± 0.001	38.581 ± 0.002
			Ashkelon_6	rod	7	2107	121	618	957	4	36		556	274	346	18.659 ± 0.005	15.678 ± 0.004	38.735 ± 0.011
			Ashkelon_7	cut ingot	3	1034	44	637	701	1	31	51	52	77	1	18.826 ± 0.001	15.692 ± 0.001	38.904 ± 0.002
			Ashkelon_8	sheet	6	814	31	700	51		8		134	20	36	18.677 ± 0.008	15.678 ± 0.007	38.763 ± 0.017
			Ashkelon_9	sheet	4	1989	42	506	311	2	5	6	16	280	47	18.451 ± 0.004	15.667 ± 0.003	38.555 ± 0.007
			Ashkelon_10		8	5071	34	471	58	1	31	5	1673	188	1119	18.745 ± 0.005	15.682 ± 0.004	38.817 ± 0.012
			Ashkelon_11		6	2102	38	1505	96	1	20	3	275	370	264	18.792 ± 0.006	15.694 ± 0.005	38.933 ± 0.013
			Ashkelon_12		5	1137	56	600	155		27	33	137	18	4	18.748 ± 0.002	15.689 ± 0.001	38.832 ± 0.004

(*continued on next page*)

Table B.1 (*continued*)

Period	hoard	bundle	sample ID	type	Cu wt%	Pb	Au	Bi	Fe	Co	Ni	Zn	As	Sn	Sb	^{206}Pb/^{204}Pb ± 1σ	^{207}Pb/^{204}Pb ± 1σ	^{208}Pb/^{204}Pb ± 1σ
Iron Age IIA	**Beth Shean 1029 a+b**		BS 1029_1	rod	1	1876	27	523	2553	19	1	3	18	19	7	18.583 ± 0.006	15.665 ± 0.004	38.672 ± 0.010
			BS 1029_2	cut ingot	2	4250	9	3047	682		1	7	10	5	4	18.957 ± 0.003	15.698 ± 0.002	39.018 ± 0.006
			BS 1029_3	ingot	5	6484	27	4714	317	1	27	6	7	33	4	18.669 ± 0.001	15.675 ± 0.001	38.738 ± 0.003
			BS 1029_4	ingot	1	734		409	325			6	5	2	3	18.921 ± 0.006	15.678 ± 0.005	38.943 ± 0.015
			BS 1029_5	ingot	1	5274		3748	157			4	13	4	4	18.960 ± 0.008	15.703 ± 0.008	39.034 ± 0.020
			BS 1029_6	ingot	2	1874	30	1028	83		7	9	4	38	3	18.652 ± 0.007	15.678 ± 0.006	38.718 ± 0.017
			BS 1029_7	rod	2	3748	13	1525	1413	3	2	5	10	5	5	18.790 ± 0.002	15.678 ± 0.003	38.850 ± 0.008
			BS 1029_8	cut ingot	0.4	28975	10	10543	192			1	3	1	2	18.989 ± 0.003	15.701 ± 0.002	39.050 ± 0.007
			BS 1029_9	cut ingot	2	1899	39	4046	376	1	1	4	4	1	2	18.808 ± 0.003	15.683 ± 0.003	38.878 ± 0.007
			BS 1029_10	cut ingot	2	10544	4	1956	232	1	1	12	12	2	3	18.703 ± 0.026	15.696 ± 0.020	38.826 ± 0.050
			BS 1029_11	cut ingot	2	2310	65108	220	600	1	1	4	6	3	4	18.875 ± 0.008	15.668 ± 0.007	39.015 ± 0.018
			BS 1029_12	cut ingot	0.3	516	103	829	1182	2	2	1	3	10	1	18.940 ± 0.006	15.689 ± 0.006	38.976 ± 0.014
			BS 1029_13	cut ingot	0.2	16323	11	4699	556	1	1	10	1	1		18.983 ± 0.002	15.697 ± 0.003	39.038 ± 0.005
			BS 1029_14	cut ingot	2	3210	104	782	506	1	20	2	5	5	3	18.522 ± 0.001	15.679 ± 0.001	38.638 ± 0.002
			BS 1029_15	token	0.1	42099	32	2539	79			4	3	1	1	18.980 ± 0.005	15.692 ± 0.004	39.015 ± 0.010

separated from the rest of the ore. The lead-silver alloy was subsequently heated again with hot air in a cupel. In this second stage, denoted cupellation, the silver was separated from the lead which quickly oxidized and sank to the bottom of the vessel. Most trace metals were concentrated in the oxidized lead (litharge), and therefore the chemical composition of silver can reveal little about the parent ore (Pernicka and Bachmann, 1983). Lead isotope (LI) analysis, therefore, remains the main method used to associate between silver in archaeological items and its original lead ore source (for an overview of the method, its limitations, relevant bibliography and major ore sources in the region see Eshel et al., 2019). The Levant has no silver sources, and the nearest ones are in Anatolia and Greece (Stos-Gale and Gale et al., 1990; Eshel et al., 2019). Therefore, provenancing silver using LI provides an excellent proxy for identifying long distance trade.

In this study, many of the sampled silver items were mixed with copper. The chemical compositions were therefore used primarily to identify mixing and alloying, rather than for sourcing the ores. In addition to the absence of many elements (e.g., Zn, As, Sb, Sn) from pure cupelled silver (see above), silver produced from a single ore can vary significantly in its bulk chemical composition (Pb, Cu, and occasionally Au and Bi), depending on the heterogeneity of the ore and the production process (Pernicka and Bachmann, 1983).

2. Compositional Groups

In this paper we define two compositional groups:

2.1 Silver unalloyed with copper. Cupelled silver usually contains up to 5.5% Cu, 3% Pb, 0.5% gold (Au) and 3% bismuth (Bi) (Pollard and Bray, 2015; Eshel et al., 2019). Most other elements (arsenic [As], antimony [Sb], tin [Sn], nickel [Ni] and zinc [Zn]) are expected to be removed (or nearly removed) during the cupellation process (Pernicka and Bachmann, 1983).

2.2 Silver-copper alloys. Silver-copper alloys, which are at the focus of the present study, are expected to contain more than 5.5% Cu, and additional elements contributed by the added copper. Copper is produced by direct smelting and therefore retains many elements from the original ore, including traces of As, Sb, Sn, Ni and Zn. In this study, however, As and Sb concentrations cannot serve as an indication for the origin of the copper, since they could have been added separately (see more below and in the main text). As for other metals, it is generally assumed that Au, Bi, Ni and Zn are natural contributions, namely reflect the original composition of the silver and copper ores. Bismuth and Au are expected to be contributed both by silver and by copper, while Ni and Zn by the copper ore minerals only, since they are removed by the production process of silver (Meyers, 2003; Hauptmann, 2007; L'Heritier et al., 2015; Pernicka, 2014).

3. Elemental compositions in Ag–Cu alloys

Based on the above, we present below the main elements that are significant for this study of Cu–Ag alloys:

3.1 Arsenic and antimony. These are mostly known from 4th–3rd-millennia contexts, through their presence in arsenical copper, which was an important alloy in the development of copper metallurgy since the Chalcolithic period. They are evident, for example, in the early 4th millennium Nahal Mishmar hoard in Israel's Judean Desert (Shalev and Northover, 1993). In most regions around the Mediterranean, arsenical copper disappeared from the archaeological record in the Middle Bronze Age (the early second millennium BCE), with the introduction of tin bronzes (references in Rehren, Boscher and Pernicka, 2012). The use of arsenical bronze in the Late Bronze and Iron Ages was rare, occasionally selected for the silvery tint which it created. In the Caucasus, As and Sb were used to produce copper alloys during the local Bronze and Early Iron Ages (Pike 2002; Meliksetian and Pernicka, 2010; Mödlinger and Sabatini, 2017). Arsenical copper was also recorded to have been used since ~1400 BCE to produce arrowheads in Tarsus in Anatolia (Dardeniz, 2007), and was used in ornaments in Lori-Berd, Armenia (12th century BCE; Meliksetian et al., 2011), in Slovenian pendants generally dated to the beginning of the 1st millennium BCE (Paulin and Orel, 2003), and also in the Eastern Alps (8th century BCE; Giumlia-Mair, 2008). The use of As in Cu–Ag alloys was recorded previously only in the 3rd millennium BCE "royal tomb" at Arslantepe, Anatolia (Hauptmann et al., 2002). As mentioned in the main text, arsenical copper artefacts were common for millennia, throughout the Old, Middle and New Kingdom periods in Egypt, for example, in mirrors and particular statuettes (Vandier and Félix, 1972; Riederer, 1978; Schorsch, 1988; Masson-Berghoff et al., 2018).

Arsenic (and in some cases also antimony; Fig B1) must have been added intentionally, rather than with the added copper (Giumlia-Mair, 2008:111; Thornton et al., 2009; Meliksetian and Pernicka, 2010; Sabatini, 2015; Boscher, 2016; Radivojević et al., 2018; Rademakers et al., 2017). Arsenic concentrations decreased by oxidation and evaporation upon production and re-melting of copper alloys (Bray and Pollard, 2012; Sabatini, 2015; Mödlinger and Sabatini, 2016). Their concentrations in copper smelted with speiss are expected to be higher than in copper produced from Fahlore (As–Cu ores) but As concentrations in copper are limited by its maximum solubility of ~7–8 wt.% (Scott, 2011; Sabatini, 2015). Alloys with low/moderate As and Sb concentrations are either natural or the product of mixing As-rich with As-poor alloys, or possibly the result of re-melting As-rich alloys (Sabatini, 2015).

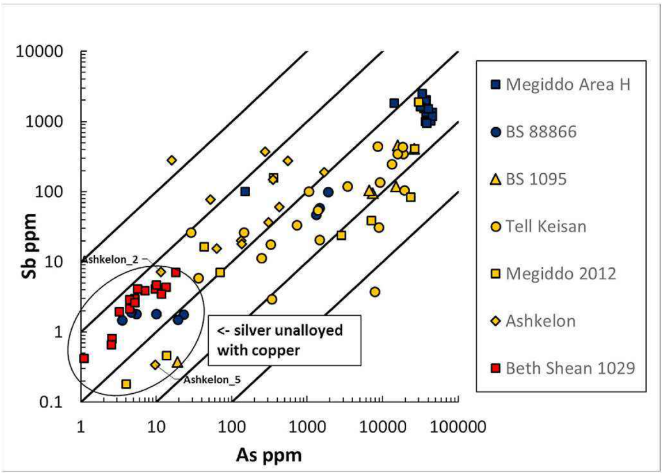

Fig. B1. Antimony vs As. LB III silver items are in blue, Late Iron Age I silver items are in yellow, and Iron Age IIA in red. The ellipse marks chemical ratios expected for silver unalloyed with copper.

3.2 Bismuth. The concentrations of Bi in silver can reach up to a few percent, depending on Bi concentrations in the lead ore and the quality of the cupellation process (L'Heritier et al., 2015). Our items have generally low Bi concentrations. Bismuth displays a negative correlation with Cu, suggesting that Bi was diluted by Cu addition (Fig. B1).

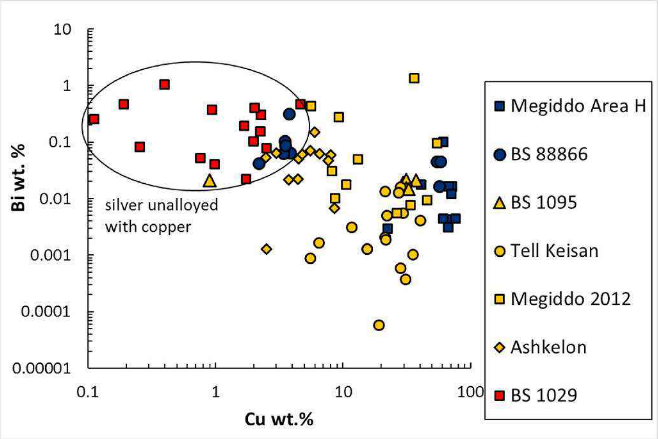

Fig. B.2. Bismuth vs Cu. LB III silver items are in blue, Late Iron Age I silver items are in yellow, and Iron Age IIA in red. The ellipse marks chemical ratios expected for silver unalloyed with copper.

3.3 Gold. Au is potentially the most telling element for the chemical characterization of silver ore sources, since it is present in Ag-rich lead ores at a fixed and unique concentration for each ore, and Au/Ag ratios remain unchanged from the lead ore onto the smelted lead-silver alloy, the cupelled silver, and the final product (Pernicka and Bachmann, 1983; Meyers, 2003). It was thus successfully used to differentiate between lead-silver ore types (Moorey, 1999; Pernicka, 2014). It has been suggested that the unusually high Au/Ag ratios in silver from the southern Levant were indicative of a yet unidentified Au-rich ore source, perhaps in Iberia (Stern, 2001; Meyers, 2003; Wood et al., 2019). However, as we have previously shown, gold was occasionally added to the silver through re-melting of electrum (Ag–Au alloy) jewelry, and therefore its concentrations in the silver cannot be uncritically used for provenance (Eshel et al., 2018, 2019). This claim is further sustained by the results of the current study: (1) The Au-rich artefacts (>0.1% Au) from the BS 88866 hoard are broken jewelry items (an earring and a decorated bracelet, see Fig. B.3, Table B.1). (2) In the Tell Keisan hoard, the five Au-rich items are all from the same bundle (numbered #8 in the Israel Antiquities Authority records), while the lead isotope analysis of these items display a large diversity and does not point to a specific ore source (Fig. B4), namely, there is no correlation between composition and provenance of Au-rich silver in this bundle and hoard. (3) Au-rich items were sampled from both the LB III and Late Iron Age I periods, but mostly from the latter (Fig. B3), suggesting that due to shortage in silver in the latter period, more jewelry–which tends to be Au-rich (Eshel et al., 2018)–was used or re-melted for use as currency. (4) The 16 high-Au samples in this study have negative Au–Cu correlation, suggesting that, like Bi, Au was diluted by Cu addition (Fig. B3). This suggests that Au in the Au-rich samples was mixed with silver post-production and prior to the addition of Cu.

Based on the above, we conclude that Au concentration cannot be used as a proxy for provenance of silver, nor for the Ag–Cu alloys in this study. Notably, lead-isotope values of all high Au items do not point to a specific ore source (Fig. B4). To the contrary, these Au-rich items have isotopic values that range from the Taurus/Aegean/Laurion to the Sardinia/Arabah ores. This is in accordance with our conclusions in Eshel et al. (2019), and in contradiction to Wood et al. (2019).

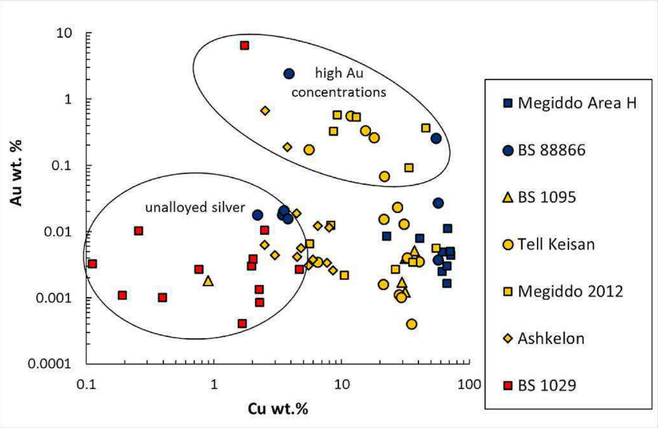

Fig. B.3. Gold vs Cu. LB III silver items are in blue, Late Iron Age I items are in yellow, and Iron Age IIA in red. The ellipse marks chemical concentrations expected for unalloyed silver, and items with high Au concentrations.

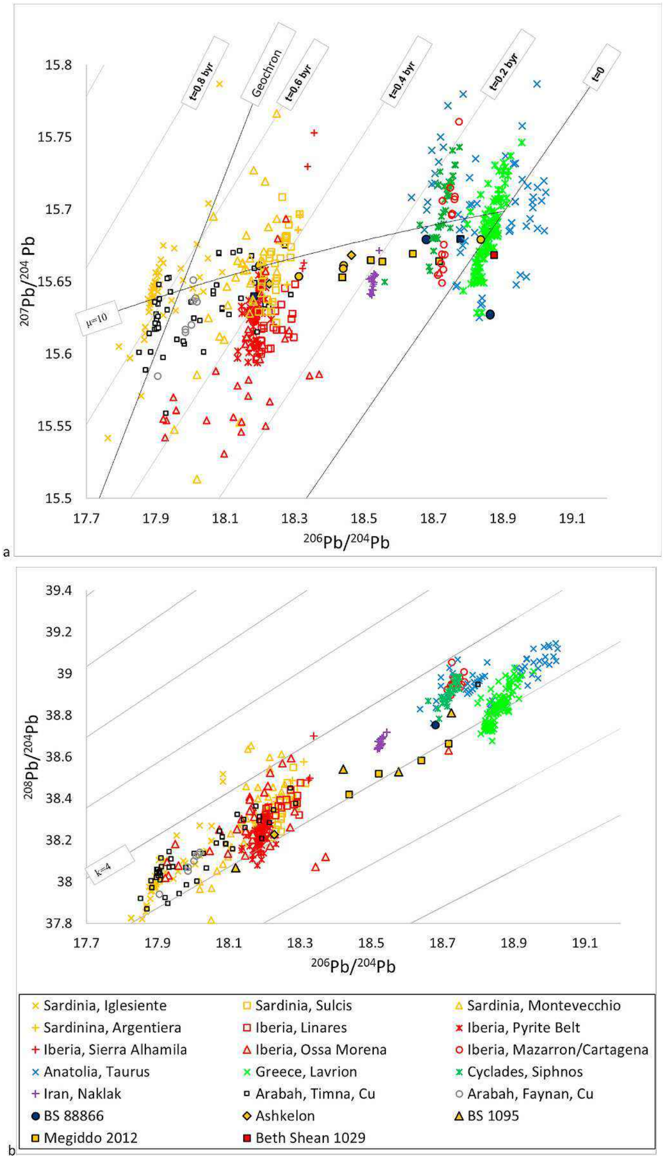

Fig. B.4. (a) ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb of Au-rich (>0.1%) silver items, of the Megiddo H, Beth Shean 88866, Ashkelon, Tell Keisan, Megiddo 2012 and Beth Shean 1029 hoards (b) ^{208}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb Au-rich (>0.1%) silver items, of the same hoards (Table B.1). LB III silver items are in blue, Late Iron Age I silver items in yellow, and Iron Age IIA items in red. The results are plotted against model ages of the major silver sources in the Near East and around the Mediterranean potentially exploited for silver in the Bronze and Iron Ages. Colors of lead ores are distributed geographically: Red – Iberia (Linares, Pyrite belt, Sierra Alhamila, Ossa Morena and Mazzaron/Cartagena; Graeser and Friedrich 1970; Stos-Gale, 2001; Tornos and Chiaradia, 2004; Murillo-Barroso, 2013); Yellow – Sardinia (Igelsiente, Sulcis, Montevecchio and Argentiera; Boni and Koeppel, 1985; Stos-Gale et al., 1995; Begemann et al., 2001; Valera et al., 2005; OXALID); Purple – Iran, Naklak (Nezafati and Pernicka, 2012); Blue – The Aegean (Laurion and Siphnos, Gale and Stos-Gale, 1981; Stos-Gale and Gale 1982) and Green – Anatolia, Taurus (Yener et al., 1991; Sayre et al., 1992), Black and Grayscale – copper ores in the Arabah (DLS in Faynan and Amir and Avrona formations in Timna; Gale et al., 1990; Hauptmann et al., 1992; 2007).

3.4 Nickel. Silver-copper alloys in this study have a wide range of Ni concentrations (0<[Ni]<20,000 PPM; Fig. B5). Nickel is one of a few elements that is absent in silver, and is not significantly altered during copper smelting; it thus reflects the copper-ore composition (Pernicka, 2014). In the LB III hoards, Ni values are rather constant, ranging between 200 and 900 ppm. In Late Iron Age I hoards, Ni values are much more diverse, suggesting that further mixing with Ni-rich copper occurred (Fig. B5). Positive correlation between Ni and As concentrations suggests, however, that Ni was contributed both by Cu and As, which were deliberately added to some of the silver items, and therefore cannot be considered a reliable tracer of Cu (Fig. B5; see more in the main text).

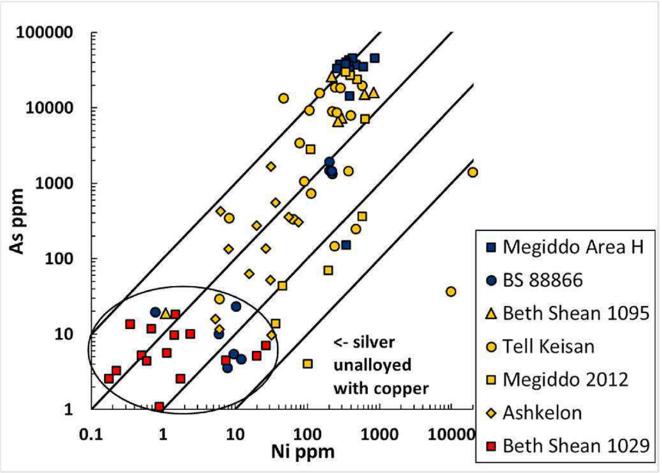

Fig. B.5. Arsenic vs Ni. LB III silver items are in blue, Late Iron Age I silver items are in yellow and Iron Age IIA items in red. The ellipse marks chemical ratios expected for silver unalloyed with copper.

Funding

This research was supported by a grant of the Gerda Henkel Foundation in Germany (Grant AZ 05/F/16; awarded to A.G. and Y.E.), by Hebrew University internal grant to Y. E., and by the Nathan Rotenstreich scholarship and additional scholarships from the Research Authority of the University of Haifa, awarded to T. E.

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