Supplementary Information for
A multi-analytical approach to unveil Early Bronze Age population dynamics and metal exchange networks at the foot of Mount Vesuvius

Maria De Falco[1,*], Paola Aurino[2], Claudio Cavazzuti[3*], Chiara Lucarelli[4], Caterina Canovaro[4], Federico Lugli[1], Alessandra Sperduti[5,6], Viola Cecconi[7], Ivana Angelini[8], Gilberto Artioli[4], Anna Cipriani[1]

[1] Department of Chemical and Geological Sciences, University of Modena and Reggio Emilia, Via Giuseppe Campi, 103, Modena, 41125, Italy
[2] Soprintendenza Archeologia Belle Arti e Paesaggio per la provincia di Cosenza, Piazza Valdesi, Cosenza, 87100, Italy
[3] Department of History and Culture, Alma Mater Studiorum-University of Bologna, piazza San Giovanni in Monte 2, Bologna, 40144, Italy
[4] Department of Geosciences, University of Padua, Via Giovanni Gradenigo, 6, Padova, 35131, Italy
[5] Bioarcheological Service, Museum of Civilizations, piazza Guglielmo Marconi 14, Rome, 00144, Italy
[6] Department of Asian, African and Mediterranean Studies, University of Naples "L'Orientale", Piazza S. Domenico Maggiore 12, Naples, 80134, Italy
[7] Department of Odontostomatological and Maxillofacial Sciences, Sapienza University of Rome, Via Caserta 6, Rome, 00161, Italy
[8] Department of Cultural Heritage: Archaeology and History of Art, Cinema and Music, University of Padua, Piazza Capitaniato, 7, Padova, 35139, Italy
* maria.defalco@unimore.it, claudio.cavazzuti3@unibo.it

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Archaeological context

Rescue excavations, carried out between 2014 and 2019, along a 15 km trait of the high-speed train line Napoli-Bari ('Napoli-Cancello' variant) have led to the identification of several prehistoric sites in the northern part of the Campania plain, north of Naples, in the hinterland of Acerra (Fig. 1 main text; [1,2]), most of which dated to the Late Copper and Early Bronze Age (late 3rd and early 2nd millennium BC).

In particular, these excavations allowed to detect different phases and modes of occupation of the area between two main eruptive events, namely 'Agnano-Monte Spina' (according to present dates set between 4420 ± 58 BP[3,4]; 3335-2913 cal. BC, 2σ, recalibrated with IntCal 20) and 'Avellino Pumices' (1906-1829 BC cal. 2σ[5,6]).

Here two important burial sites, AC3_620 and AC3_970, are investigated. They are both located at the north-eastern edge of Acerra municipality, in a heavily cultivated area (Fig. S1), and they occupy a strategic position, alongside a natural route, the ancient river Clanis valley, that connected north and south Campania and provided access to the Apennine valleys. The two cemeteries are approximately 1 km far from each other and have slightly subsequent chronologies based on the material culture and eruptive stratigraphy: AC3_620 cemetery spans between the Final Copper Age and the Early Bronze Age 1 (c. 2400-2000 BC), while AC3_970 cemetery is set in the Early Bronze Age 2 (c. 2100-1800 BC).

The Final Copper Age – Early Bronze Age cemetery: AC3_620. The 2016-2018 excavation of AC3_620 identified the traces of a cemetery explored for approximately 4500 m^2, situated 200 m north of a partially coeval village (AC3_600) investigated for more than 7500 m^2. The cemetery was set on a natural plateau on top of the volcanic deposits of the Agnano-Monte Spina Phlegraean eruption (3335-2913 cal. BC, 2σ). The necropolis includes 127 single flat inhumations laid in large sub-rectangular pits and arranged with a homogeneous NW-SE orientation, in some cases preserving the original covering of stones and limestone pebbles. The burial area is characterized by a strong spatial planning in which the tombs respect precise spaces by being arranged in regular, parallel, and structured alignments. Rarely the tombs overlap or cut each other.

According to typo-chronology of the archaeological materials, the cemetery was set between the end of the Copper Age and the beginning of the Bronze Age, corresponding to the transitional period between the local Laterza and Palma Campania cultures. The cemetery shows external influences, especially Bell Beaker pottery[1,7]. Grave goods are not always present, and usually comprise ceramic vessels, often intentionally fragmented, metal and bone ornaments, as well as weapons, whose typology are discussed in detail in the following sections. The pottery record is characterized by shapes and decorations typical of the final phases of Laterza culture, Bell Beaker-type decorations, and the typical Palma Campania 'hourglass-shaped base', as well as cups on high foot. In some tombs these different markers were found together, suggesting a gradual stylistic evolution entangled with external influences. At least two phases can be distinguished based on the material record and organization of the tombs. An earlier Late Copper Age phase is characterized by larger subrounded tombs with no cover in stone, located at the north and south margin of the necropolis, and in two cases at the center; it is represented by 4 burials displaying ceramic grave goods typical of the local Laterza culture. The second phase, probably already starting at the end of the Copper Age given the Bell Beaker influences, finally peaks in Bronze Age 1, with the onset of a regularly planned burial ground, with sub rectangular tombs with stones as cover or in the infill, rare grave goods, mostly metal or ornaments, and occasional ceramic deposition in the infill.

The Early Bronze Age cemetery: AC3_970. AC3_970 burial site comprises 46 tombs located in the proximity of a settlement dated to the same phase (Early Bronze Age 2) and attributable to the Palma Campania culture. The cemetery was in use before and after the destructive eruption of Avellino Pumices (1906-1829 BC cal. 2σ[5,6]), as indicated by the volcanic stratigraphy. In fact, some of the inhumations were covered by the pumice layers, while others were cut on top of them. Similarly to AC3_620, burial pits are of sub-rectangular shape and often preserve traces of calcareous stones on top of the grave or arranged in the infill in an orderly manner. The tombs, all oriented NW-SE, are arranged in two rows in the northwestern portion of the cemetery, and are, instead, much more concentrated in the central portion. Inhumations can be single or multiple, with individuals deposed side by side or one on top of the other. Grave goods are generally

scarce, consisting mainly of pottery, often fragmented, and rare metal objects, such as daggers, pins, and one single miniaturized halberd. The ceramic repertoire includes carinated bowls, biconical jars and the peculiar cups on decorated high foot and is typical of the Palma Campania culture, attested in Southern Italy between the late-3rd and mid-2nd millennium BC.

Materials

Metal objects. Metal objects were found in 25 graves of the earlier cemetery (AC3_620), relatively dated to the Early Bronze Age 1 (tombs 292, 295, 299, 303, 307, 312, 318, 380, 383, 384, 385, 386, 400, 402, 427, 430, 438, 450, 452, 457, 489, 490, 494, 495, 502) and in 7 tombs from the Early Bronze Age 2 cemetery (tombs 321, 324, 340, 341, 355, 367, 374). The peculiarity of these metal objects lies both in their rare appearance in Southern Italy and in the concentration of such prestigious objects with strong foreign influences at a single site.

The types of bronze objects attested are: pins, daggers/halberds, rivets, awls, hair rings, and necklace elements. Daggers and ornaments such as pins were preferred for geochemical and isotope analyses given their better state of preservation. The daggers can be divided in two groups: the first relatively dated to Early Bronze Age 1 composed of 4 specimens from AC3_620; the second is relatively dated to Early Bronze Age 2 and represented by 3 specimens from AC3_970. A further miniaturized, or probably reused, halberd was found in T. 374; it displays a unique typology and is characterized by the partial preservation of a decorated bone or antler haft. All the daggers display a rounded hafting plate, several rivet holes, and a triangular blade. Daggers from AC3_620 (EBA1) are finely decorated and can be linked to two main types mostly circulating in Northern Italy with scattered presences in Southern Italy: the Ledro type (variety A, [8]: 21-23, tav. 11 n. 144-148) and the Jesi type ([8]: 29-30, tav. 14 n. 209-219). It must be noted that the association with specific types established in the Italian Peninsula, mostly based on the abundant findings from Northern Italy, is only indicative since the scarcity of specimens from Southern Italy has not allowed the definition of a refined typology[8,9]. Only two other sites in Campania region yielded similar finely decorated daggers dated between the Early Bronze Age 1 and 2 (also post Avellino Pumices eruption), in particular the contexts of Gricignano d'Aversa ([10]: 226-9, fig. 1-3, fig. 2.3) and Nola-Via Cimitile ([9]: 192, fig. 3A n. 10).

Daggers from AC3_970 (EBA2) are undecorated and can be associated with two main types attested in the Italian Peninsula: the Mincio type ([8]: 23-24, tav. 12 n. 155-162) and the Murgia-Timone type ([8]: 24-27, tavv. 12-13 n. 163-191). These types are slightly later than the previous ones and can be dated to the full Early Bronze Age 2. They are mostly attested North of the Po River, in the Garda area, and increasingly in Central and Southern Italy, such as in the site of Gricignano d'Aversa in Campania, both in pre and post Avellino Pumices eruption burials (pre t. 26 Area Sportiva, and tombs 7 and 15 post[11]). Daggers of the same types are attested also in the pre-eruption cemeteries of Ostaglio[12] and Aversa (ITIS tomb 2 sounding 2[11]) and in the post-eruption one of S. Abbondio[13].

Several burials yielded metal ornaments rarely attested elsewhere in Campania. In particular: pins, hair rings and part of necklaces. Tomb 295 yielded a lozenge-shaped pin which has a wide circulation in the Early Bronze Age, in particular in Northern Italy ([14], p. 93, tavv. 1-2). Another type of pin attested in the cemetery and dated to the Early Bronze Age is represented by disc-headed pins (*Scheibenkopfnadeln*) either undecorated or with embossed circles. In Tomb 427 two disc-headed pins were found on the right side of the skeleton near the shoulder. The discs are decorated with circles on both sides, alongside the edge and in the center. Tomb 495 yielded a disc-headed pin and other types of ornaments such as a hair ring and two beads. This type of pins is generally rare in Southern Italy, but further examples are attested in two Early Bronze Age contexts in Campania. An undecorated specimen was found in Tomb 26 in the Palma Campania cemetery of S. Abbondio, Pompei ([10], p. 229) and a highly decorated one from the area of Salerno, in the site of Oliva Torricella ([10], p. 226-227, fig. 1.4, 2.6, pp. 230-231) with parallels from the area of the Upper/Middle Danube, Lower Austria, Moravia and Slovakia between the end of the Early Bronze Age A1 and the beginning of Early Bronze Age A2 ([15], pp.143-147, fig. 13.1-4). The distribution and chronology of the disc-headed pins is detailed in the main text (Fig. 6). A roll headed pin is also found in the AC3_620 cemetery from tomb 303. This type of pin has a wide geographical distribution and long-time span of use, from the Early Bronze Age to later phases ([14]: 110, 13). Their distribution clusters in the Garda area and Alpine arc, but

spans also in the rest of the Peninsula, with a certain frequency in the Po plain ([14]: 99-110, tavv. 6-9).

Chemical and microstructural results of bronze objects

Chemical results (SEM-EDS and EPMA) and the most relevant microstructural observations are reported in Supplementary Dataset S1. For the majority of the 20 objects, it was possible to take samples without alterations and therefore they can be considered representative of the composition of the artifact. Only three samples (ace-pg1, ace-pg5 and ace-pg6) were severely or completely corroded. For this reason, they are not comparable with the other results obtained, but are reported only in Pb isotopes diagrams.

All objects are realized in bronze and, in Figure S2, the different amount of Sn for all typologies is reported (EDS results, in Supplementary Dataset S1). Particularly, the content of Sn for pins and awl covers the range between 1.5-9.2 wt.%. It is possible to notice how most of the pins found in the AC3_620 cemetery have the lowest Sn values, around 2÷3%. Their mechanical properties are fairly similar to technically pure Cu (such as elasticity and ductility). Among these pins, ace-sp18 is characterize by the presence of coring (Sn 1.60-4.62 wt.% - EPMA results) and the chemical etching highlights (Fig. S3a) the presence of slightly deformed grains, twins, and slip lines. These characteristics suggest the application of different steps of working and annealing and the heating as a final step, in order to increase its plasticity[16,17]. The presence of coring indicates that complete homogenization of the metal was not achieved.

Only one pin from AC3_620 cemetery is characterized by higher Sn values (around 8÷10%), comparable with those shown by the pins and the awl of AC3_970 cemetery. In this case, the Sn content permits to obtain superior hardness and mechanical strength[18–21] and it could be coherent with the sampling point. In Fig. S3b-c are reported the chemical etching of pin ace-sp14 and the awl ace-sp12. They show a similar structure formed by small grains, slightly deformed, with twinned and slip lines and flattened sulfides along a preferential orientation. These evidences indicate that the metal was subjected to working and annealing and heating as a final step to increase its plasticity[16,17]. It is probable that this process was too short and did not remove all impurities. Moreover, adding Sn to Cu alters the color of the alloys and with amounts of around 3÷4% the typical reddish color of copper predominates and 5÷10% Sn produces a golden-yellow bronze[18], thus highlighting a possible aesthetic choice.

Regarding the weapons, two daggers of AC3_620 cemetery, the dagger and the halberd of AC3_970 cemetery present Sn values in range of 10.6-14.5 wt.%. Consistently, these concentrations are coherent with the necessity to obtain a harder and more resistant alloy. As example, in figures S3d-e are reported the chemical etching of dagger ace-pg7 and the halberd ace-pg15 respectively. For the dagger the metallography reveals the presence of slip lines and twins and small grains that suggest the application on metal of several steps of hammering and annealing. The presence of inclusions and segregations in the α-phase indicate that alloy annealing and homogenization have not been achieved. For the halberd, the etching highlights the presence of deformed grains with some strain lines that suggest a heavy working of different steps of hammering and annealing. The absence of inclusions and segregations in the α-phase suggest that a homogenization was achieved. In both cases the final step is the hardening to decrease the plasticity of the metal and increase its hardness and mechanical characteristics [16,17,22].

The rivet ace-rib9 (AC3_970 cemetery) and the dagger ace-pg20 (AC3_620 cemetery) have, respectively, Sn equal to 6.2- and 6.3 wt.%, which could be justified with the need to have less hardness and mechanical strength. The chemical etching of the rivet (Fig. S3f) highlights slightly deformed grains, twins and slip lines. This evidence indicates that the metal was subjected to working and annealing and heating as a final step to increase its plasticity[16,17]. The presence of inclusions and segregations in the α-phase indicate that alloy annealing and homogenization have not been achieved.

The Figure S4 shows the different inclusions and segregations observed and analyzed with SEM–EDS and EPMA analyses and discussed in the main text.

Fig. S1. Satellite image of the area of the two cemeteries taken into consideration: A) AC3_620, Final Copper Age - Early Bronze Age 1 cemetery; B) AC3_970, Early Bronze Age 2 - Palma Campania culture cemetery (base image Google Earth 2024, Data SIO, NOAA. U.S. Navy, NGA, GEBCO, Image Landsat/Copernicus, ©2024 Google, modified using the Free and Open Source software GIMP 3.0 available at https://www.gimp.org/).

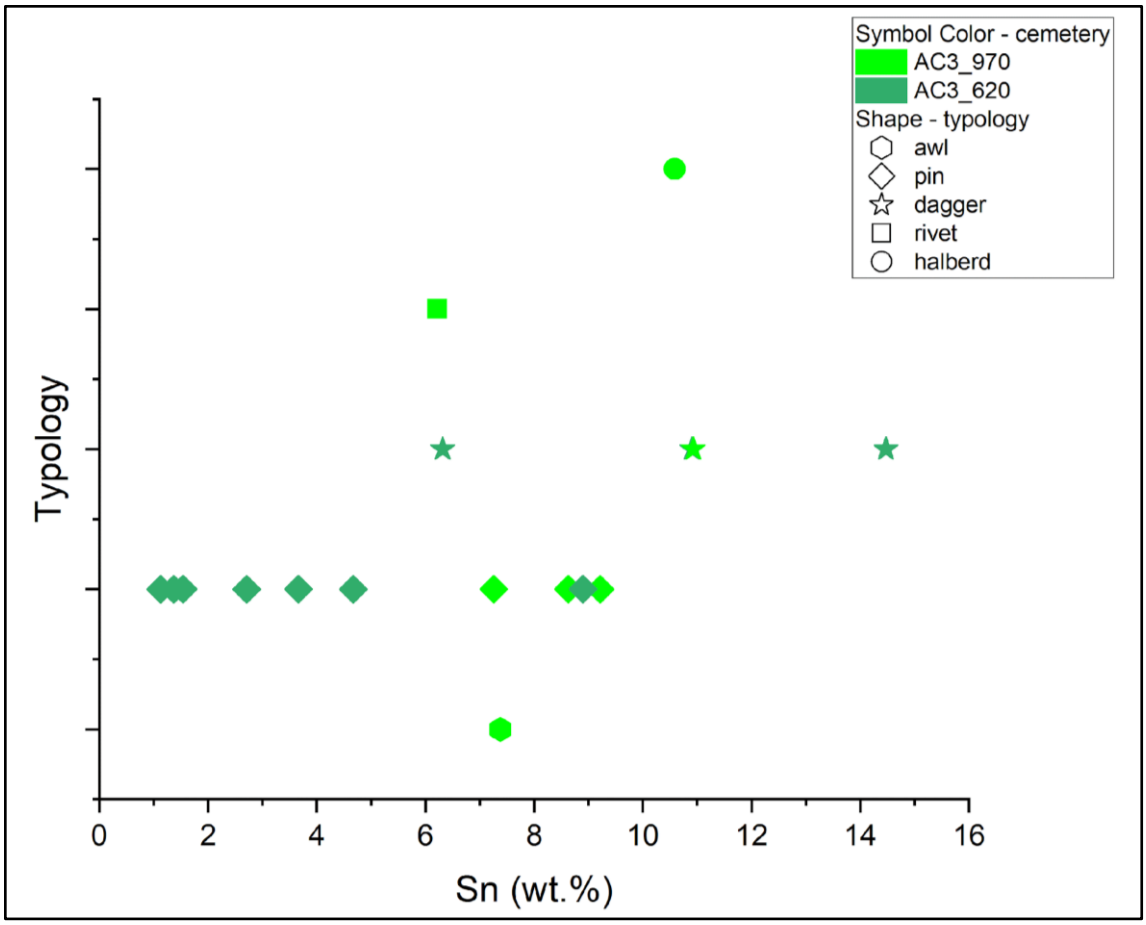

Fig. S2. Different amount of tin for each category of metal objects analyzed.

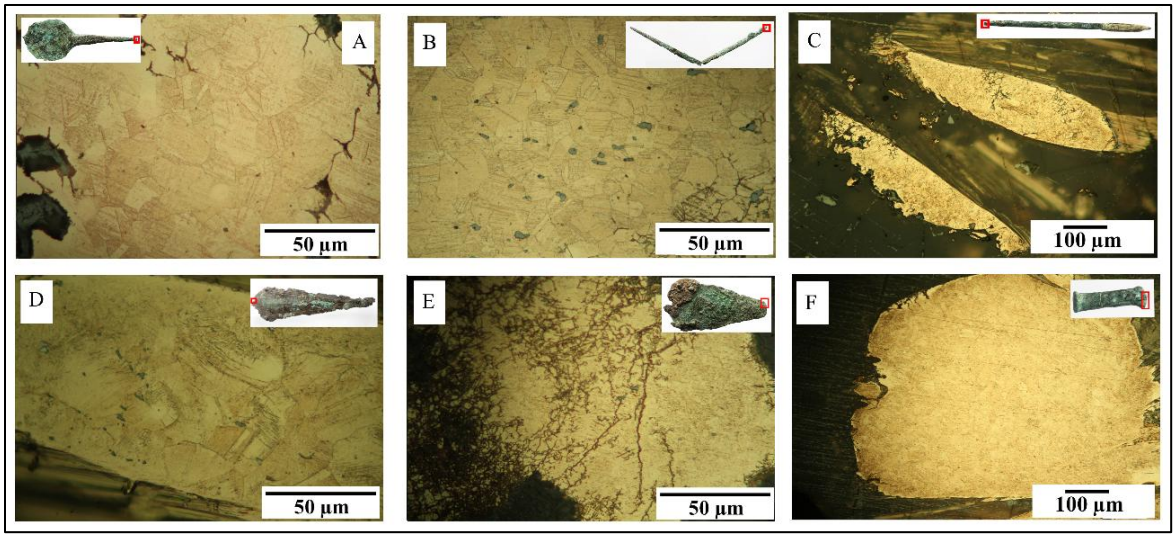

Fig. S3. a) RL-OM cross-section of the metallography of the pin ace-sp18 highlights the presence of slightly deformed grains, twins and slip lines; **b-c)** RL-OM cross-section of the metallographies of the pin ace-sp14 and the awl ace-sp12 respectively show small grains, slightly deformed, with twinned and slip lines inside and flattened sulfides along a preferential orientation; **d)** RL-OM cross-section of the metallography of the dagger ace-pg7 highlights the presence of slip and twins lines and small grains and flattened sulfides along a preferential orientation; **e)** RL-OM cross-section of the metallography of the halberd ace-pg15 highlights the presence of strain lines; **f)** RL-OM cross-section of the metallography of the rivet ace-rib9 displays the presence of slightly deformed grains, twins and slip lines and flattened sulfides along a preferential orientation.

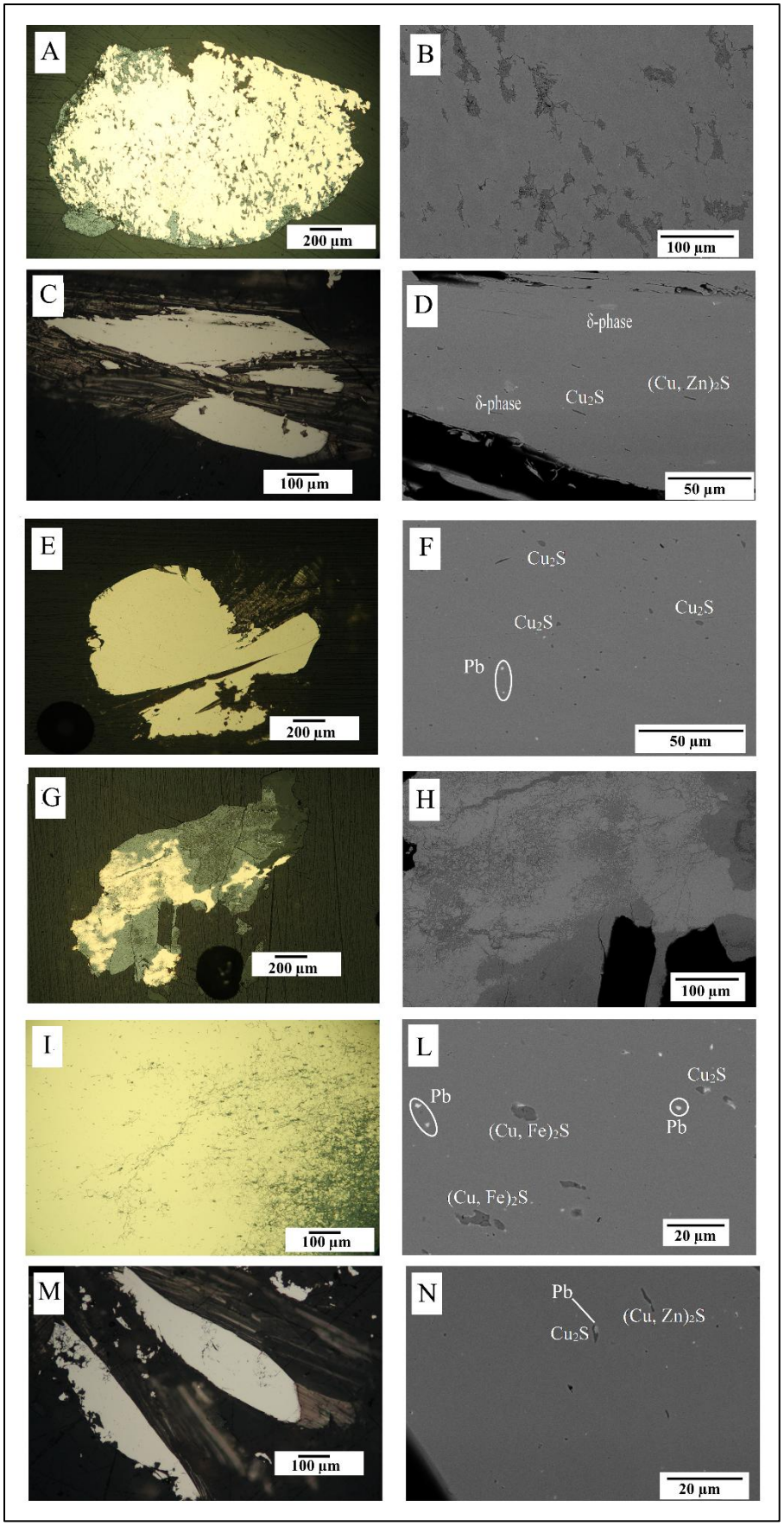
A
200 µm
B
100 µm
C
100 µm
D
δ-phase
δ-phase
Cu2S
(Cu, Zn)2S
50 µm
E
200 µm
F
Cu2S
Cu2S
Cu2S
Pb
50 µm
G
200 µm
H
100 µm
I
100 µm
L
Pb
(Cu, Fe)2S
Cu2S
Pb
(Cu, Fe)2S
20 µm
M
100 µm
N
Pb
Cu2S
(Cu, Zn)2S
20 µm

Fig. S4. a-b) RL-OM cross-section and BSE image of the pin ace-sp18 showing a homogeneous α-phase without inclusions and segregation and the presence of coring; **c-d)** RL-OM cross section and BSE image of the dagger ace-pg7 highlighting the presence a heterogeneous α phase with the presence of sulfides of the Cu_2S and $(Cu, Zn)_2S$ type, δ-phase and Pb segregations; **e-f)** RL-OM cross-section and BSE image of the rivet ace-rib9 showing the presence a heterogeneous α phase with the presence of Cu_2S sulfides and Pb segregations; **g-h)** RL-OM cross-section and BSE image of the halberd ace-pg15 emphasizing a homogeneous α-phase without inclusions and segregation. Corroded areas are also visible; **i-l)** RL-OM cross-section and BSE image of the pin ace-sp14 highlighting the distribution of sulfides of Cu_2S and $(Cu, Fe)_2S$ types and Pb segregations. A corroded area is also visible in the right side of the RL-OM photo; **m-n)** RL-OM cross-section and BSE image of the awl ace-sp12 emphasizing the distribution of sulfides of Cu_2S and $(Cu, Zn)_2S$ types and Pb segregations.

Table S1. Detail of the human remains analyzed from the two cemeteries and $^{87}Sr/^{86}Sr$ values.

Cemetery	Grave n.	Estimated sex	Estimated age-at-death	Metal grave goods	Sample for Sr isotope analysis	87Sr/86Sr corr	2se	Pre/Post AP eruption
AC_620	292	Male?	30-40	Dagger	M1	0,707654	0,000005	Pre AP
AC_620	293	Male?	>30		M1	0,708073	0,000008	Pre AP
AC_620	319	Undetermined	25-35		M1	0,707796	0,000007	Pre AP
AC_620	380	Female?	30-40		M1	0,707921	0,000006	Pre AP
AC_620	384	Undetermined	30-40		M3	0,708017	0,000005	Pre AP
AC_620	400	Female?	30-40		M1	0,707791	0,000004	Pre AP
AC_620	402	Undetermined	24-30		M1	0,707954	0,000006	Pre AP
AC_620	404	Undetermined	30-40		M1	0,707981	0,000007	Pre AP
AC_620	427	Undetermined	generically young adult	Pin	M1	0,707737	0,000005	Pre AP
AC_620	438	Undetermined	30-40	Pin	M1	0,707784	0,000007	Pre AP
AC_620	450	Female??	16-20	Dagger	M1	0,707945	0,000006	Pre AP
AC_620	452	Undetermined	30-40		M1	0,707782	0,000005	Pre AP
AC_620	453	Undetermined	20-30		M1	0,707779	0,000007	Pre AP
AC_620	457	Undetermined	>30		M1	0,707859	0,000005	Pre AP
AC_620	460	Male?	>30		M1	0,70774	0,000005	Pre AP
AC_620	482	Undetermined	30-40		M1	0,707803	0,000007	Pre AP
AC_620	489	Undetermined	30-40	Dagger	M1	0,707821	0,000005	Pre AP
AC_620	494	Undetermined	24-30		M1	0,707988	0,000008	Pre AP
AC_620	495	Undetermined	>30	Pin	M1	0,707901	0,000005	Pre AP
AC_620	504	Undetermined	24-30		M1	0,70791	0,000004	Pre AP
AC_620	525	Undetermined	30-40		M1	0,70786	0,000005	Pre AP
AC_620	531	Male??	30-40		M1	0,707795	0,000006	Pre AP
AC_970	323	Undetermined	generically adult		M1	0,707895	0,000005	Uncertain
AC_970	324	Male?	generically adult		M1	0,707846	0,000005	Uncertain
AC_970	326	Undetermined	25-30	Dagger	M1	0,708087	0,000005	Uncertain
AC_970	327	Male?	20-30	Dagger	M1	0,707953	0,000007	Uncertain
AC_970	336	Female?	30-40		C	0,708242	0,000005	Uncertain
AC_970	340	Undetermined	20-25	Pin stem/awl	M1	0,707931	0,000008	Pre AP
AC_970	341	Undetermined	25-35	Awl	M1	0,707823	0,000006	Pre AP
AC_970	349	Undetermined	20-30		M1	0,708136	0,000007	Pre AP
AC_970	350	Undetermined	generically adult		M1	0,707903	0,000006	Uncertain
AC_970	355	Undetermined	20-30	Pin stem	M1	0,708304	0,000005	Pre AP
AC_970	360	Male	30-40		M1	0,707873	0,000003	Post AP
AC_970	367	Undetermined	generically adult	Rivets	M1	0,707834	0,000004	Post AP

Table S2. Summary table of the possible areas of provenance of raw materials, artifacts models and individuals in the two cemeteries analysed. Tin and copper sources in italic are debated. The numbers in brackets indicate the number of objects for which the specific copper provenance is proposed.

	Copper	**Tin (?)**	**Models**	**People**
EBA1 AC3_620	Tuscany (5) *Uncertain (3)* Balkans (1) Iberia-Sardinia (2)	Cornwall/Devon, UK NW-Central Iberia Brittany, France Iran Tajikistan Kazakhstan Kyrgyzstan Afghanistan *(Massif Central, France* *Erzgebirge* *Balkans* *Sardinia, Italy* *Tuscany, Italy* *Anatolia)*	Northern Italy + Disc-headed pins: N Italy Transalpine and Upper/Middle Danube area	Local
EBA2 AC3_970	Tuscany (4) *Uncertain (2)* Balkans (2) Iberia-Sardinia (1)		Northern Italy	Local + Non Local

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