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Metalworking Evidence from a Late Antique Context in the Forum of Grumentum

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ABSTRACT
This paper is a preliminary report on metallurgical activity detected in the Forum of the ancient city of Grumentum (Basilicata, Italy). In the Late antique period, an area next to one of the most important temples of the square was turned into a metalworking structure, which has yielded a set of hearths, metallurgical remains, and some tools. The results of archaeometrical investigation on the debris are reported and discussed, together with a general analysis of the archaeological context, also in comparison with other similar evidence detected elsewhere in Italy.

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1.0 Introduction

In ancient times, *Grumentum* (today's Grumento Nova, Basilicata, Italy) was an important settlement of the upper Agri Valley at the crossroad between commercial routes connecting the Thyrrenian and the Ionic Sea, thus being an important trade centre from its origins (Giardino 1992). (Figure 1)

The city was founded in the first decades of the 3rd century BC by Lucanian and Roman people during the Roman expansion in Lucania and became a battle scene during the Second Punic war. After destruction in the Social war, it was rebuilt as a Roman colony, after the Laws of Caesar on colonisation, around 59 BC (Tarlano (2014). In the second half of the 1st century BC, the city was equipped with new walls with towers, roads, an aqueduct, a theatre, an amphitheatre and thermal baths. The Forum, core of its political and commercial life, featured a Basilica and three temples: the so-called "C" Temple (most likely devoted to the imperial cult), the Capitolium and the Round Temple. (Figure 2)

Grumentum remained a thriving centre throughout the Imperial period, and its urban layout did not undergo significant changes until the 4th century AD, when some public spaces were abandoned; despite a moment of crisis and consequent reorganisation of its urban spaces during the first half of the 4th century AD, the urban area gradually became depopulated from the 6th century AD, and it was completely abandoned by the 9th century (Cirelli et al. 2013). The excavations (2005 - 2014) carried out by the University of Verona in different sectors of the ancient square enhanced our knowledge of the organization and evolution of the Forum, and brought to light an archaeological sequence ranging from the 2nd century BC to the present day (Mastrocinque 2013). Traces of metallurgical activity were detected since the first excavation campaign in an area adjacent to the C Temple, with a relevant number of iron and copper alloy working remains (Bison 2013), whilst no traces of structures connected with metalworking were found until 2012, when a rich set of pits and hearths was discovered and investigated, together with a large quantity of slags, and some objects which can be directly related to metalworking: all these finds are part of a consistent ensemble connected to intense metallurgical activity.

2.0 Materials and methods

2.1 The Workshop

The area was excavated by the Soprintendenza Archeologica della Basilicata in 2004. At that time a thick layer of arable land was removed, revealing various walls. After an initial cleaning in 2005, it was then investigated by L. Pozzan between 2011 and 2013. (Figure 3)

The place where the metalworking activity took place is located beyond the southern side of the *Porticus* delimiting the Forum square: in its first arrangement, it seems to be an open, probably roofless space, connected through an access with the colonnaded porch. After the second half of the 1st century AD, a small porch open to the south, with L- shaped pillars made of stone blocks, and brick columns, was added on the eastern side. Metallurgical activities developed in this area at a later stage. Finally, the construction of some masonry structures lead to the closure of the passage to the *porticus*, and consequently to the Forum, meaning that the space was divided to form smaller rooms. After the dismantling of the

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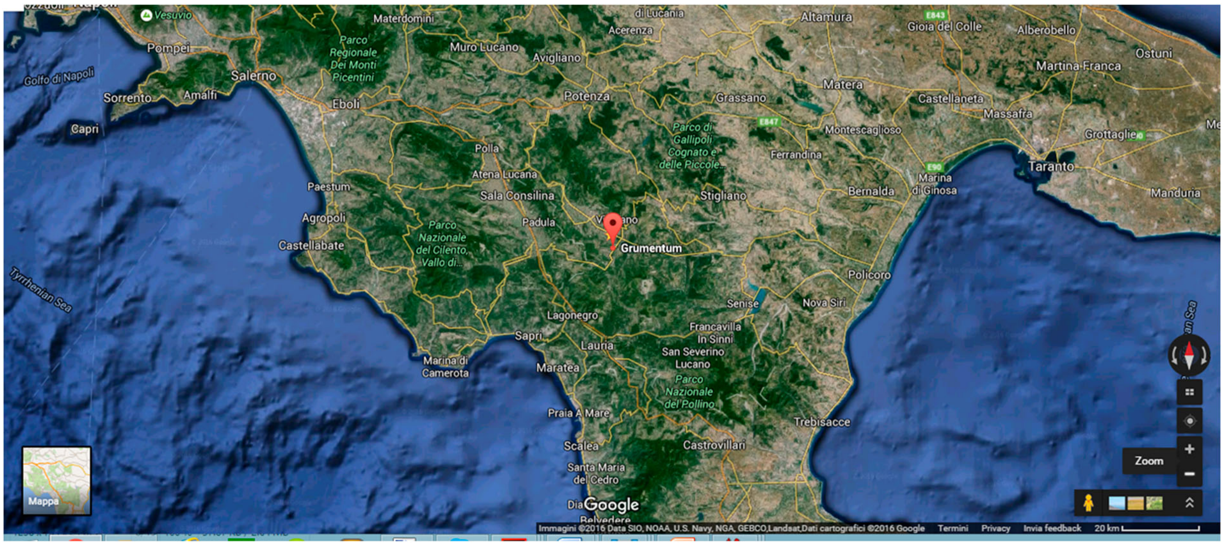

Figure 1. Localisation of Grumentum in Southern Italy (via Google Maps).

metalworking plant, the area was turned into a necropolis, as attested by the discovery of five burials. Stratigraphic evidence and preliminary data from the study of coins and pottery sherds suggest that the metalworking activity in this space can be approximately dated to the 5th century AD.

The workshop area is set upon very dark, well-trod soils, rich in coal and metallurgical remains that expanded considerably during the use of the furnaces. Two separate productive phases were identified. The first phase (Figure 4), not entirely explored yet, is characterized by three large superimposed rectangular pits (2.20×1.60 m and 0.50 m deep; 2.60×1.80 m and 0.50 m deep), showing clear signs of heath exposure. The walls of the pits were probably coated with clay and pebbles. The function of the pits is not yet clear, but they could have been used for the casting of bronze objects, probably by placing moulds at the bottom and filling the pit with sand to hold the moulds in place, as in metalworking sites such as those in Avenches (Serneels and Wolf 1999), Verona (Grassi 2015) and Autun (Chardron-Picault and Pernot 1999).

Slightly later, a second phase of activity took place directly above the obliterated pits (Figure 5), which features a large number (at least 15) of overlapping, subcircular-shaped ground level hearths, measuring

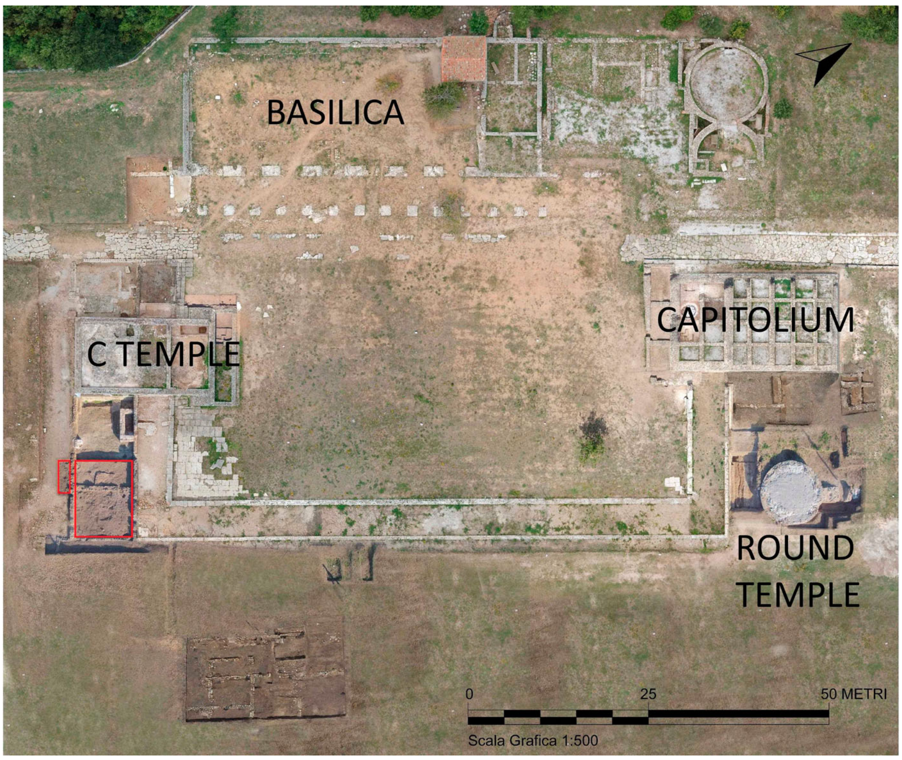

Figure 2. An overview of the Forum area: the workshop is highlighted in red.

Figure 3. The workshop viewed from South (photo L. Pozzan).

between 80 cm and 2 m in diameter and 10-20 cm in depth. This context reflects an organization scheme that seems to have been common in many other metal-working sites dating from the end of the 1st century to the 7th century AD, such as those found in Milan (Grassi 2011), Rome, on the North-Eastern slopes of the Palatine hill (Ferrandes 2013), at Piazza Venezia (Serlorenzi and Saguì 2008), at the Athenaeum of Hadrian (Anguilano et al. 2014) and Aiano Torraccia di Chiusi (Cavalieri et al. 2010).

Three pits can be attributed to this phase: the westernmost has a sub-circular shape (90 cm x 100 cm, depth 25 cm), vertical walls and a flat bottom. The walls are covered with burnt clay with visible traces of the removal of what might have been pebbles. To the East are two further oval pits, (82 × 55 cm, depth 30 cm), with vertical walls and slightly concave bottoms.

Three other large circular pits (from 1 to 1.5 m, 40-45 cm deep) have been found along the perimeter of the workshop (Nava 2008), whose belonging to this phase is uncertain. There are also two semi-circular pits found near the eastern perimeter wall, and a third of circular shape, partially investigated, placed between the pillars of the colonnade. As they do not retain traces of thermal alteration, they could have been functional to the structure in some other way. Finally, outside the colonnade, to the South, there are three further aligned sub-oval hearth bottoms, 60-70 cm large, which have a maximum depth of about 10-15 cm. Almost 100 small postholes (3-5 cm in diameter), probably belonging to partitions subdividing the space or giving shelter from the intense heat of the furnaces to those working nearby, were also found. As for the necessary water supply, two pipes came to light at the south-easterly corner beyond the workshop during preceding investigations, however it is difficult to say whether they are contemporary or not. The presence of a fountain-nymphaeum adjacent to the western side of the C Temple, whose activity lasted throughout the 4th and 5th century AD, must be also taken into consideration.

The sequence of pits and hearths in the same place within a narrow timeline seems to follow a spatial redundancy model, a common feature in many ancient artisanal activities (Vidale 1992). There seems to have been no specific place for dumping waste products, as all the debris was then used as filling and levelling material, until the metallurgical activity came to an end.

2.2 Metalworking-related Artifacts

Some tools directly related to metalworking were also recovered. All of them are fragmentary: this suggests that they were probably discarded when the activity stopped. The first phase yielded some terracotta fragments which can be tentatively identified as parts of moulds (Figure 6): from the preserved fragments it was not possible to reconstruct any shape, but considering their dimensions, they were probably used for the production of large objects.

Among the scrap, there was also a copper alloy plate with a series of holes, most likely part of an unfinished object (Figure 7).

Concerning the second phase and its hearths, the most important find is the fragment of a tuyère, even though the remaining part of it is missing. In fact, the working end – the one which usually bears heavy traces of heating and slags because inserted in the furnace (Figure 8), was probably broken as a result of deterioration caused by the exposure to intense heat: however, the morphology of the piece (width 5,8 cm.;

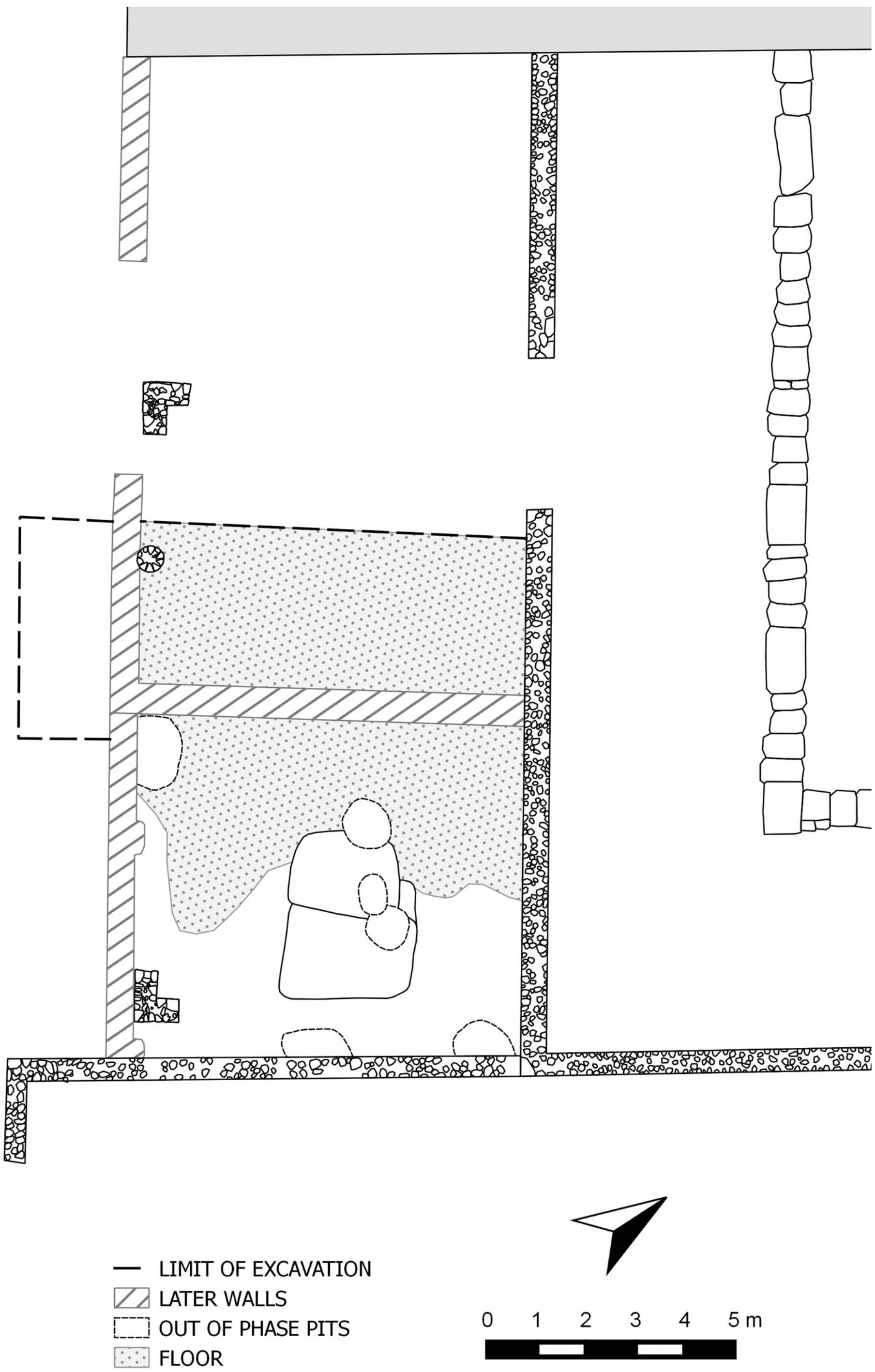

Figure 4. Plan of the structures of the first phase (drawing L. Pozzan).

diameter of the hole 1 cm.) is comparable to other such objects recovered (Giardino 2010).

There are other terracotta fragments, which might also belong to similar objects, and a very corroded and fragmentary iron object that was interpreted as a pair of tongs (Figure 9).

2.3 Metallurgical debris

A total of 192 pieces of metallurgical debris and remains were found and classified using morphometrical parameters (Angelini and Fioretti 2016). Among them, 100 pieces of so-called iron working slag, 89 remains from copper alloy working, and only 3 from lead melting, could be recognized.

The iron working remains (Figure 10) were roughly subdivided in 3 major categories: 1) Plano-convex slags (6 recorded), 2) agglomerations/clusters of slags and charcoal, 3) residues of iron objects, probably put aside to be recycled.

We can assume with some certainty that the plano-convex slags were produced by smithing.

The majority of remains from copper alloy working (Figure 11) show clear traces of charcoal, indicating that they probably cooled down among the mass of fuel inside the furnace. In this group we also identified

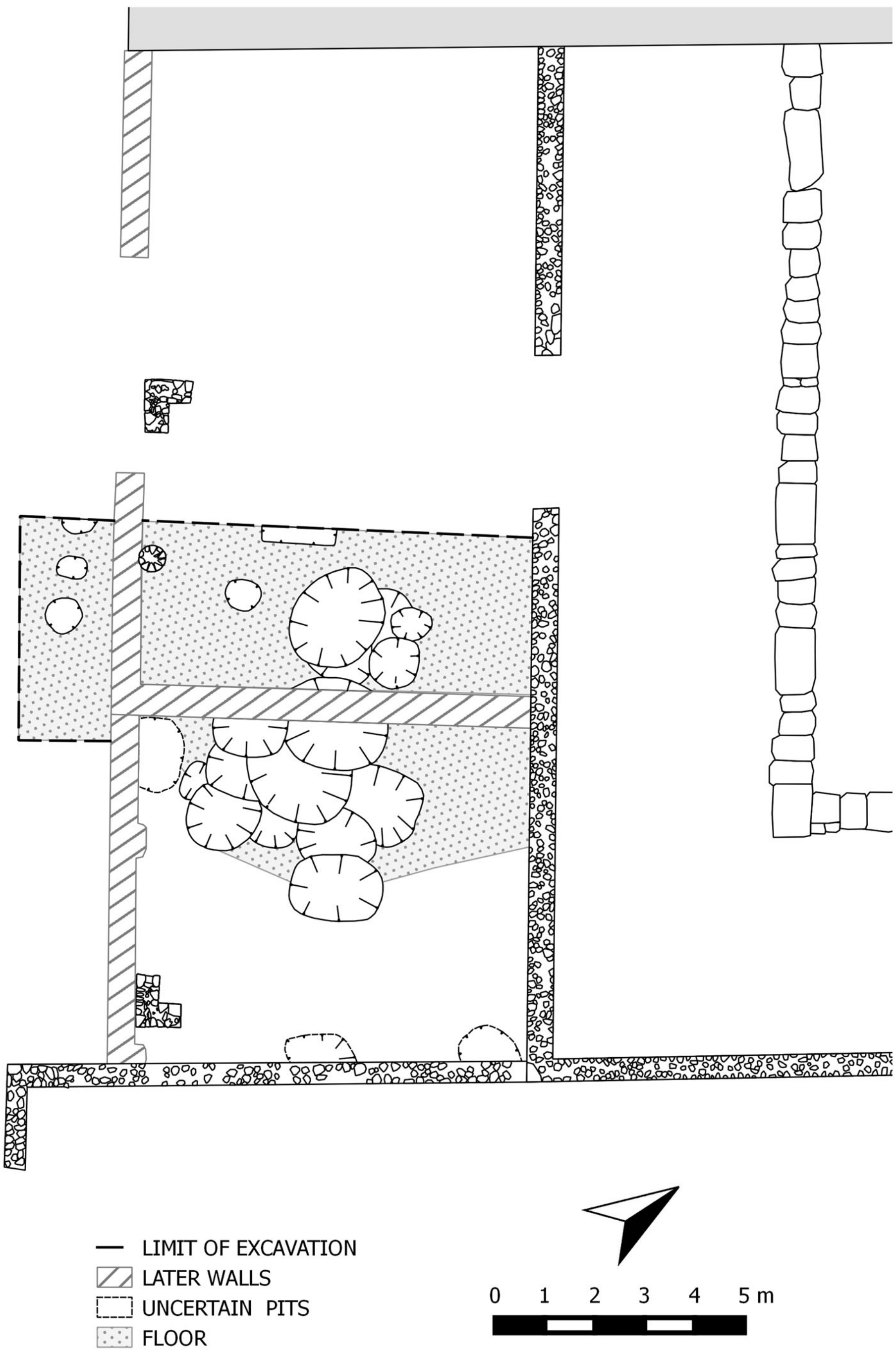

Figure 5. Plan of the structures of the second phase (drawing …L. Pozzan).

semi-corroded objects, which might have been put aside for re-melting.

Some debris originating from the alteration of the hearth wall lining caused by heat exposure was also identified.

Before obliterating the rectangular pits, careful cleaning and maintenance left a very small quantity of bronze working residues, whilst at the moment of the final abandonment of the furnaces, much larger amounts of debris were left behind.

Iron seems to have been worked exclusively in the area of the three relatively small hearths (diameter between 60 and 70 cm; depth 15 cm) on the western limit of the excavation, where no copper alloy remains were found. On the other hand, the hearths located on the eastern sector, show the opposite situation, with significantly more copper alloy residues than iron.

3.0 Results and discussion

3.1 Archaeometric Investigation of Metallurgical Residues.

This preliminary archaeometallurgical investigation focusses only on eight samples, initially identified as copper alloying debris. The samples were investigated using mineralogical and chemical analytical techniques

Figure 6. Moulds fragments (photo G. Bison).

Figure 7. Unfinished copper alloy plate (photo G. Bison).

Figure 8. Tuyère fragment (photo G. Bison).

to evaluate the type of production they relate to and the raw materials used. All of them were part of the debris filling 3 smaller pits, cut over the rectangular pits. The samples were analysed by X-Ray Fluorescence (Oxford ED 2000 with silver tube),Diffraction (Bruker D8 Advance equipped with copper tube and Lynxeye Position Sensitive Detector) and Scanning Electron Microscopy (Zeiss V35 Supra Field Emission Gun equipped with Octane Super EDAX energy dispersive spectrometer).

Figure 9. Fragmentary tongs (photo G. Bison).

The samples were recovered from three different layers, each one being the result of a different action, marked as 956, 958 and 981. Seven samples are identified as debris and metal fragments from alloys production; one from iron working, and the following results aim at identifying the raw material and the final products related to the slags. No copper–based complete objects were part of this assemblage.

Similarities are visible between the samples, and some characteristic features can be observed from individual samples, giving an interesting picture of the metallurgical processes and the raw material procurement at the site.

Sample 956-1. Detailed investigation of the sample indicates that metal bearing phases are dispersed within a vitreous silicatic fraction. The silicatic (~20%Si) fraction is enriched in calcium (~ 30%) and contains ~ 3-6% aluminium, 2-3% magnesium and potassium and ~1% iron. The metal bearing phases have different compositions and morphology:

–Newly formed leaded bronze droplets with composition (Cu 91; Sn 8; Pb0.5-1%) surrounded by a tin oxide layer (Figure 12).
–Newly formed tin oxide skeletal and angular crystals (Figure 13)

–Nead aggregations (due to segregation of the leaded bronze alloy) associated to leaded copper alloy and surrounded by pure copper and newly formed angular tin oxides (Figure 15)
–Residual copper-enriched metal surrounded by skeletal tin oxide crystals (Figure 15), small tin oxide crystals are present also in the copper-enriched area (Figure 14)

Sample 956-2. The investigation of the sample shows the diffused presence of metal droplets and the skeletal metal bearing phase within a silicatic matrix (Figure 16 and 17). The silicatic matrix is calcium iron alumino silicate (with an overall composition similar to the formula $CaAlSi_2O_{10}$).

The metal droplets around 20µm diameter show a pure copper composition (>99%) with traces of iron (~0.2%). Droplets with copper oxide composition are also detected. A range of smaller droplets are also detectable (~5 µm diameter or less),made up of lead with traces of arsenic (~0.1%) and nickel (~0.2%). Skeletal and angular newly formed crystals of tin oxide are also detected within the silicatic matrix in close proximity or separated (Figure 17) from the metal droplets. Some of the tin oxides however, do not show the angular morphology and are present in partly reacted clusters (Figure 16) indicating the "breaking up" of added aggregates of cassiterite mineral during the cementation process.

Sample 956-3. A thorough investigation of the sample (Figure 18) indicated that the sample is a fragment of leaded bronze with composition (in wt%) lead 3, tin 10 and copper 86, with traces of iron (~0.2%). Analyses of areas in proximity of a fracture show the strong presence of chlorine from post-burial alteration affecting the sample through the weathering of the alloy and

Figure 10. Iron slags (photo G. Bison).

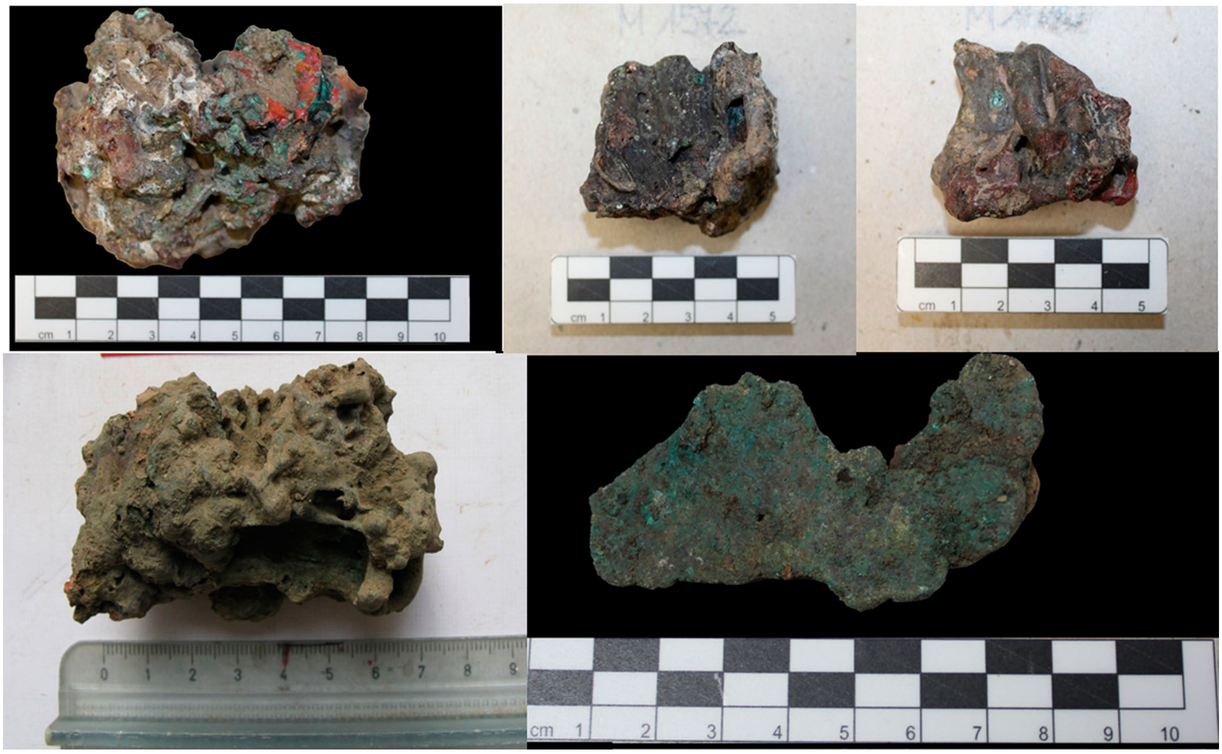

Figure 11. Copper alloy working remains (photo G. Bison).

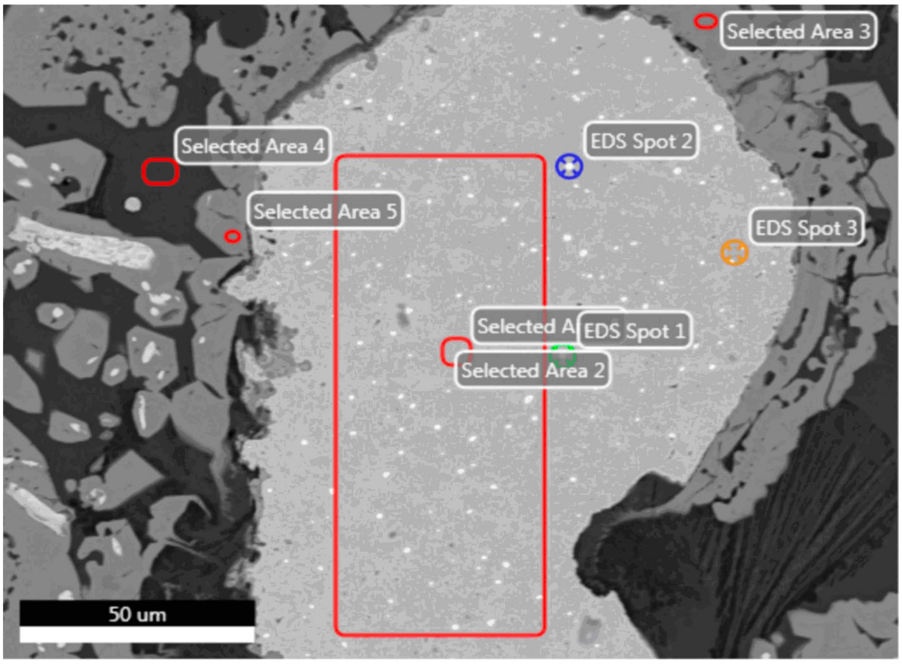

Figure 12. sample 956-1 SEM image showing leaded bronze (copper, light grey with lead white dots) surrounded by a tin oxide crown due to weathering.

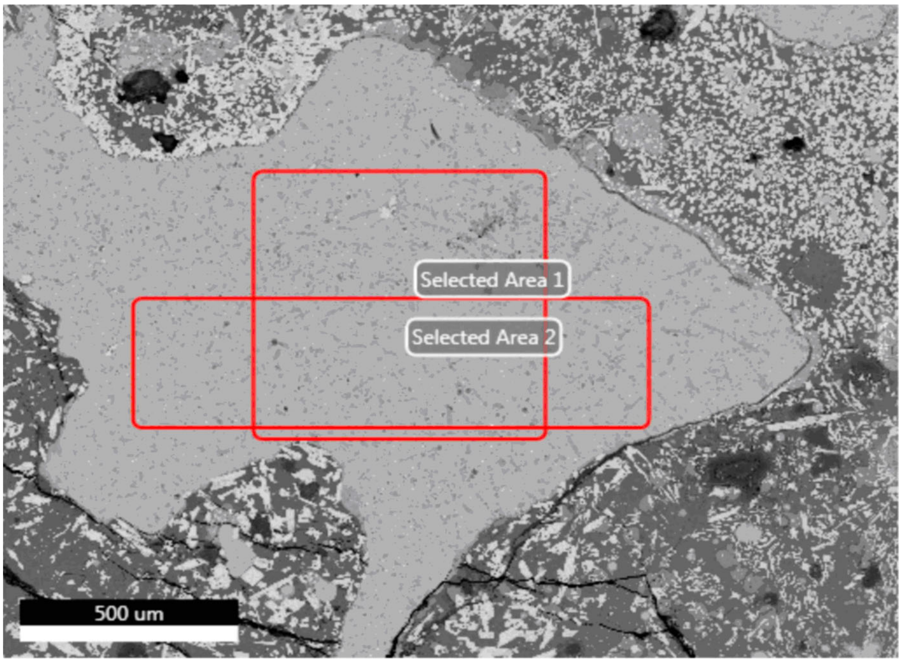

Figure 13. sample 956-1 SEM image showing residual copper (grey with acute edges and reaction bays) surrounded by fine skeletal tin oxide (white) immersed in a silicatic matrix (darker grey).

the segregation of lead in more enriched pockets. An intense process of this type leads to the loss of lead (and tin from the body of the bronze affecting the composition of the artefact). However, the internal section of the sample seems to be quite unaffected by this phenomenon, hence indicating the possibility that the composition of this sample is very close to the original composition of the alloy. The reported analyses were conducted in this specific area of the sample.

Sample 958-1. An in-depth analysis of the phases composed in this sample shows the presence of calcium silicate (including minor phosphorus), nickel iron arsenide (Ni2FeAs) with minor cobalt (~5%) and iron oxides. No copper based phases were detected in this sample, indicating the likelihood that it could be related to the iron working (possibly smithing) carried out at the site and not to the copper alloying processes.

Sample 958-2. A comprehensive examination shows metal bearing droplets with different composition diffused in a silicatic crystalline and amorphous matrix (Figure 19). The crystalline silicates are of different types:

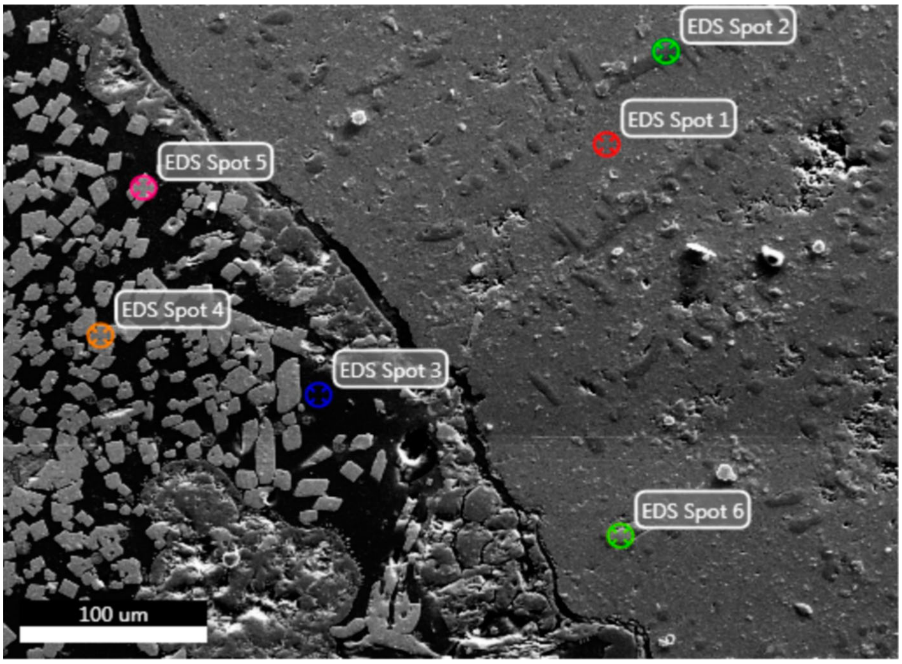

Figure 14. sample 956-1 SEM secondary electron image showing in detail the relationship between the copper-enriched area in Fig 13 and the newly formed angular tin oxide crystals. It is visible that tin oxide crystals are present also within the copper enriched area indicating that this feature results from the preferential oxidation of tin when re-melting bronze for recycling.

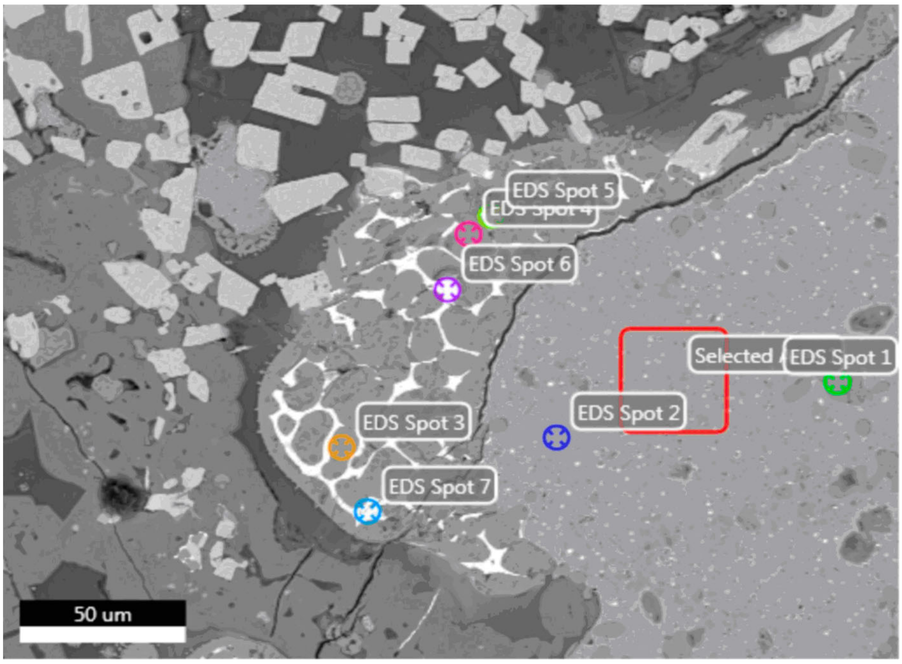

Figure 15. sample 956-1 SEM image showing copper-lead alloy (grey on the right of the image) surrounded by hopper tin oxide (light grey). Between the copper alloy and the tin oxides, an area where aggregation of lead happened around the grain is visible (white intergranular). The darker grey grains surrounded by the lead are made of pure copper.

–Large calcium/iron and calcium/magnesium silicates with a formula X_2SiO_4, where X is the sum of the cation calcium/iron or calcium/magnesium, comprising of about 5wt% aluminium),
–Skeletal calcium iron alumina-silicate with a pyroxene-like formula ($CaFe(Al,Si)_2O_6$)

The metal bearing phases can be distinguished in the following types:

–Strongly chlorinated copper,
–Newly formed droplets of bronze with compositions varying from Pb 0.5-0.6; Sn 9.3-2.4; Cu 88.9-96. 2. The strong weathering of the sample and presence of chlorine seem to explain the variability of the bronze droplets composition, which through segregation would result in poor levels of both lead and tin. However, the composition with highest tin and lowest copper is very similar to the composition detected in sample 956-3. The prill

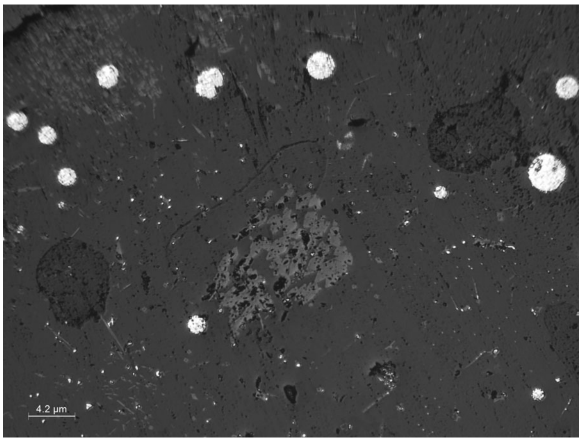

Figure 16. sample 956-2 optical microscope image showing diffused metal droplets (white in the upper part of the image) and clusters (200*300 µm in size) of tin oxides crystals partly reacted with the matrix, indicating residual cassiterite addition to the melt, similar to the features and sizes reported by Rademaker (2015).

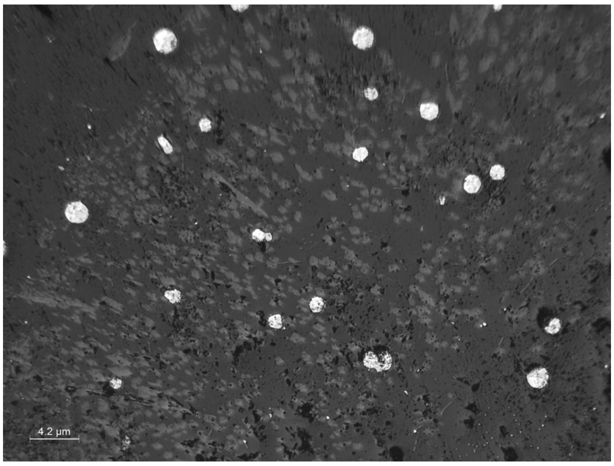

Figure 17. sample 956-2 optical microscope image showing diffused metal droplets (white) and newly formed tin oxides crystals (light grey) in the silicatic matrix.

with this specific composition ($Cu_{88.9}Sn_{9.3}Pb_{0.6}$ with a remaining 1% of Fe) is located in an area enriched in magnetite and olivines (Figure 20) with no evidence of chlorination or weathering.

- –Angular tin oxides.
- –Newly formed copper prills.
- –Newly formed bronze prills (Cu84 Sn15) containing 1.8% of iron.
- –Small newly formed prills of bronze with high tin concentration (~20%).
- –Oxidised areas of unmixed copper, tin and lead oxide phases, present in proximity of the surface of the sample seeming to indicate a further step of segregation due to weathering (oxidation and chloritisation of copper and oxidation of lead and tin).

Sample 958-3. Detailed analyses indicated that this sample, similar to sample 956-3, is a fragment of bronze with the composition Pb 0.4, Sn 5.8 and Cu 93.8, Analysis of the tin-bronze alloy (avoiding the lead grains) also shows traces of iron (~0.2%) (Figure 21).

Sample 958-4. A thorough investigation of the sample showed that this sample is also a fragment of bronze with minor lead, showing the composition Pb 0.2, Sn 3.6 and Cu 96.2

Sample 981. Analyses of the phases showed angular tin oxides, in clusters and distributed, copper oxide, copper (metal or with strong chlorinisation), and lead/copper areas distributed in a silicatic matrix (Figure 22–23). The sample showed strong similarities with sample 956-2.

Nickel was also detected in this sample, associated with copper and iron, whilst no bronze was detected in the analysed areas.

3.2 Discussion

The results indicate a possible distinction between the samples in 2 groups, plus one very dissimilar sample (Figure 24).

GROUP 1 includes samples 956-1, 2 958-2 and 981 and shows a calcium rich silicatic phase (also containing iron). The samples also contain copper and newly formed tin oxide crystals, very variable bronze alloys with copper concentrations ranging from 42 to 94%. In this group both leaded and unleaded bronzes were detected. Sample 958-2 displays strong copper oxidation.a high Fe concentration (1-2%) in the bronzes and P in the silicatic phase. Sample 981 shows minor nickel.

These samples all seem to be related to the alloying process.

The questions arising from the investigation are the following:

- –What was combined in the alloying process?
- –Was it fresh metal or scrap metal?
- –Is there enough information to distinguish the raw materials?
- –Were minerals directly added within the process?

Sample 956-1 shows the presence of residual copper enriched bronze with reaction bays embedded in the silicatic matrix, surrounded by newly formed angular tin oxide (present also in low amount within the copper-enriched area) and newly formed leaded bronze (with composition Cu 91; Sn 8; Pb0.5-1). The investigated residual copper-enriched phase surrounded by angular tin oxide seems to represent the potential addition of scrap bronze directly into the mix where during the melting process the tin is preferentially oxidised and segregates from the copper during the alloying reaction (Figure 15) as reported by Rademakers et al. (2013). Meanwhile, the newly formed leaded bronze identifies the final product of the alloying process (Figure 14). As the newly formed

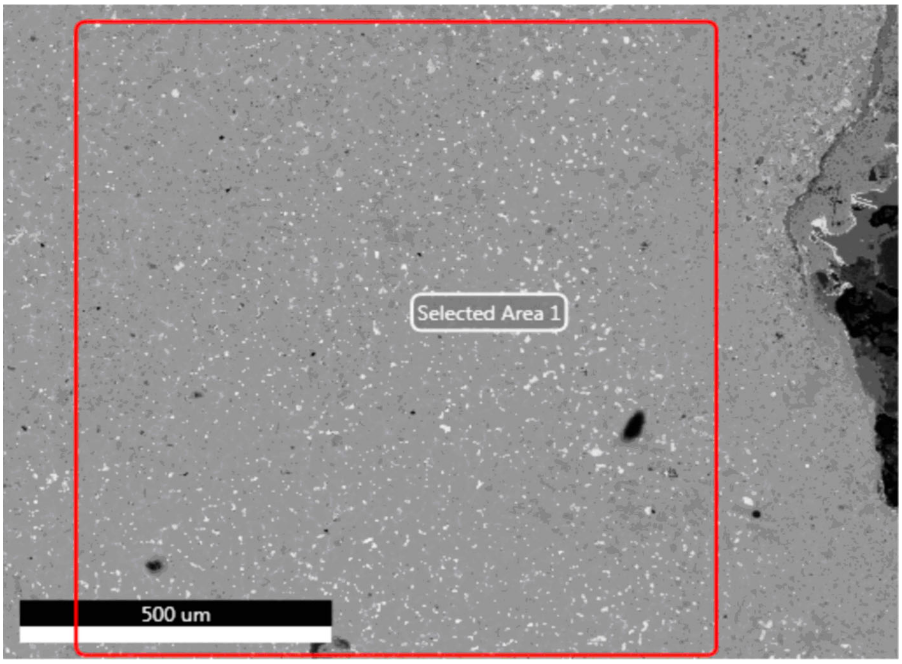

Figure 18. Sample 956-3 SEM image showing the leaded bronze alloy: in grey the tin bronze and in white the lead droplets diffused into it. On the right the reduction of lead droplets due to lead segregation is visible: this has been minimised in the selection of the area to analyse.

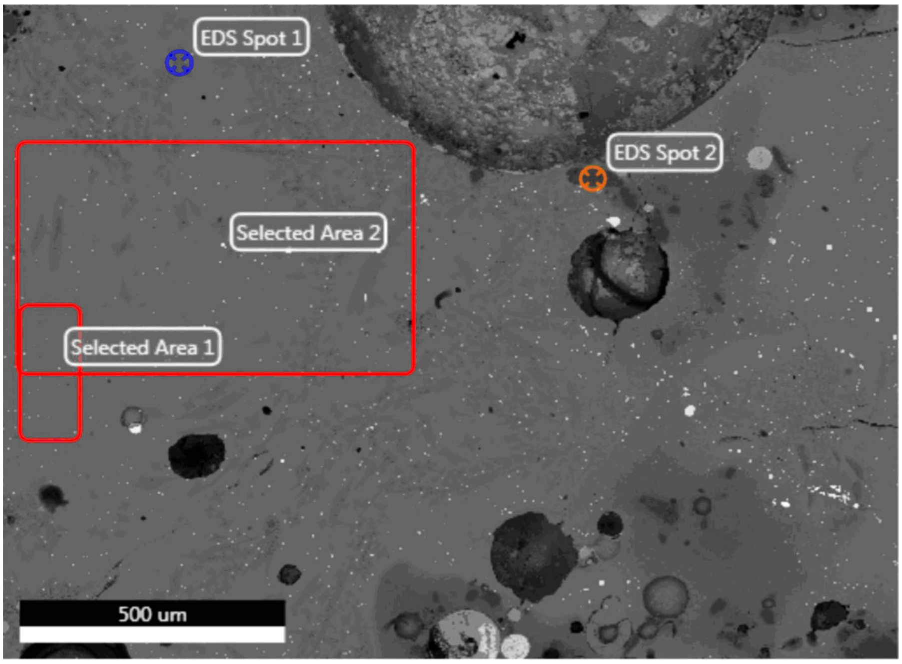

Figure 19. Sample 958-2 SEM image showing large silicatic crystals (grey), in a vitreous silicatic matrix (dark grey) and metal bearing droplets (light grey to white).

bronze prill contains 8% of tin, this might derive from an initial 10% tin bronze (represented by the composition of the metal fragment 9565-3). However, the percentage of lead below 1% seems to indicate that the final leaded bronze would contain a very low percentage of lead, this type of composition is comparable with other published objects, such as the casserole, strap plate and lamp analysed respectively by Riederer (2002), Pointing (2002) and Hook and Craddock (1996) (in Table 1). The tin oxide in this sample is mostly newly formed angular tin oxide indicating oxidation of tin during addition to the alloy. The process indicated by this sample seems to be the recycling of scrap bronze.

Sample 956-2 on the other hand shows small droplets of metallic copper and metallic lead, with a diameter of around 20 to 50 µm, and newly formed angular tin oxide as well as cluster of tin oxides (sized 200*300 µm) partially re-crystallised. As reported by Rademaker (2015) a cluster with this morphology

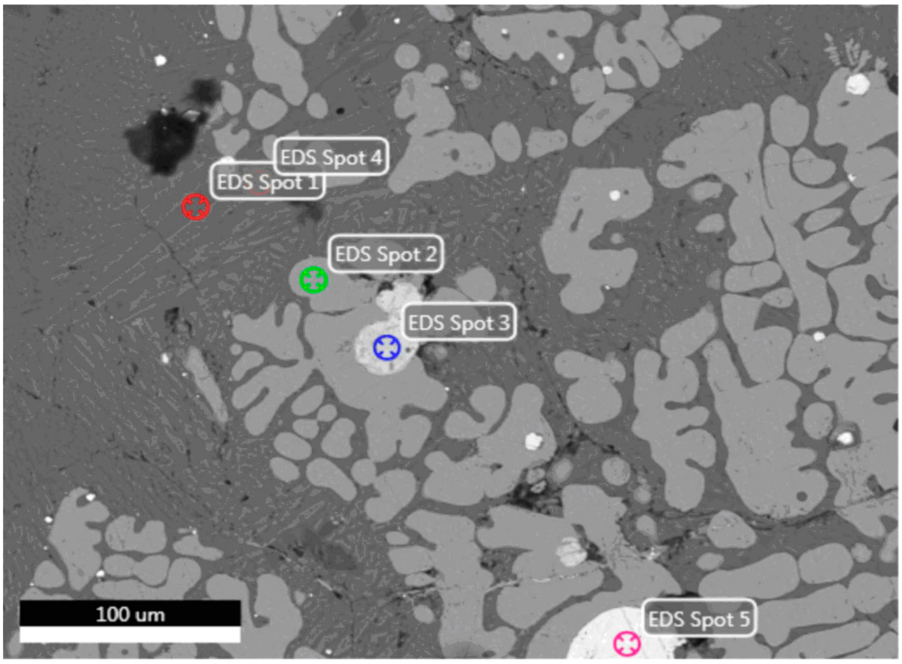

Figure 20. Sample 958-2 SEM image showing skeletal olivines and associated wustite (light grey). The white droplets at the bottom of the image are bronze with composition Pb 0.49; Sn 9.28; Cu 88.87, while the droplet in the centre of the image (EDS spot 3) has a silicatic composition enriched in tin and lead.

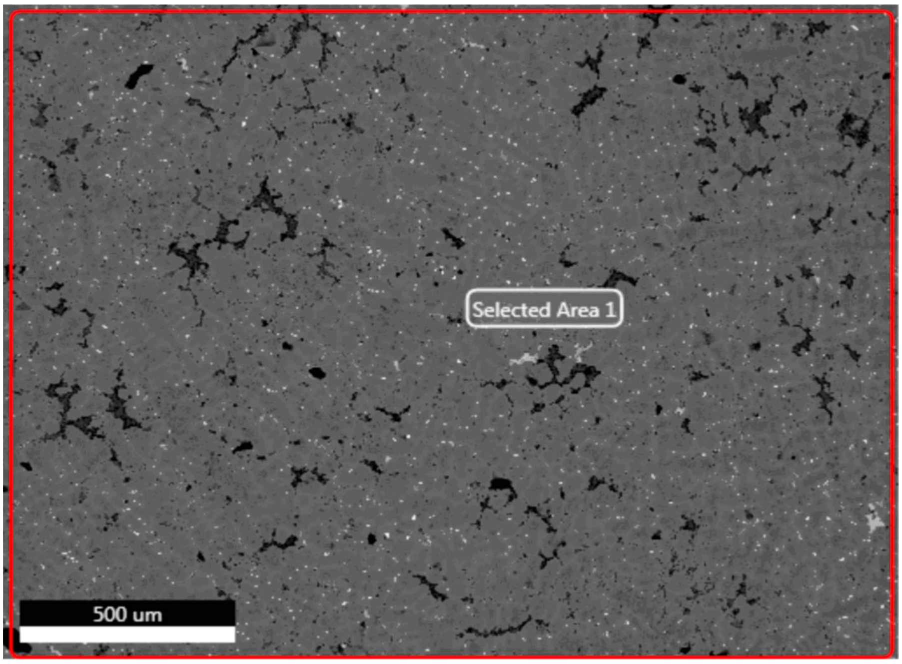

Figure 21. Sample 958-3 SEM image showing the tin bronze and the droplets of lead forming the leaded bronze.

indicates the direct addition of cassiterite in the alloying process (cementation). Hence, in opposition to the observation of sample 956-1, in 956-2 it seems that the alloying process is also obtained by the addition of mineral cassiterite to a copper/lead metal mixture.

958-2 in comparison to the other two samples shows prills with high tin (~15%), clearly indicating the addition of fresh tin to the alloying process and not the use of scrap bronze. In this case there is no evidence of ghost cassiterite, however high tin prills do not confirm the form in which the tin was added to the mixture.

981 once again shows newly formed copper metal and angular tin oxide with the addition of leaded copper, very similar to 956-2. This sample, however also shows 2% iron in association with the copper and the presence of pure copper surrounded by iron-bearing phases (such as fayalite and magnetite), suggesting a preferential ossidation of iron from an iron

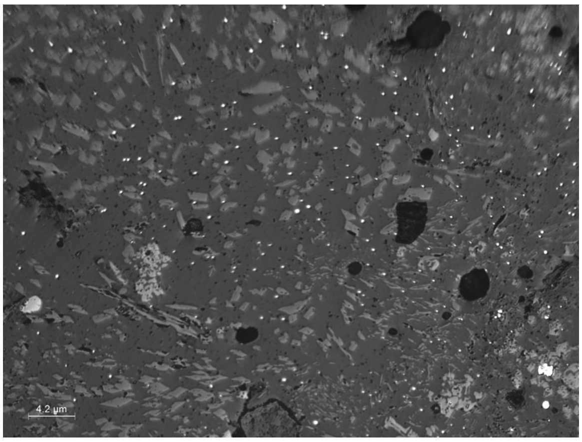

Figure 22. Sample 981 Hopper tin oxides crystals dispersed in silicatic matrix. In lighter grey cuprite crystals, in white lead aggregates. Copper is also dispersed as small droplets in the matrix (white-ish).

contaminated copper (unrefined copper). Oxidised areas of copper, tin and lead are also detected indicating that this sample underwent an environment with strongly oxidising conditions which would confirm the voluntary refinement of copper while alloying it with the other two metals to obtain the leaded bronze final product.

Samples 956-1 and 981 also display the presence of iron in association with the copper, albeit in very low percentages (<0.5%) compared to sample 958-2 just discussed. Lastly,sample 981 shows traces of nickel which seems to have a connection with the iron working sample 958-1.

GROUP 2 includes samples 956-3, 958-3 and 958-4, which are all identified as metallic fragments mainly composed of copper, tin and lead and the respective weathering products (oxides and chlorides). The composition of the alloys range from a more copper-enriched alloy (Cu 96.2%, Sn 3.6% and Pb 0.2) and more tin and lead-enriched alloy (Cu 85.7%, Sn 9,7% and Pb 3.3%) . All the samples show traces of iron (~0.2%). These compositions correspond to the variability of leaded bronzes presented in the literature (Table 1).

SAMPLE 958-1 seems to be anomalous and shows a strong association with iron working instead of copper. However, this sample provides a very important geological indication on the possible raw material used in the workshop, linked with strong nickel mineralisation (also confirmed by the detection of nickel in sample 981). This sample also contains traces of phosphorus, which are found in other samples of the assemblage. Evaluation of the geological map of the area (Figure 26) seems to point out a possible origin of a nickel rich ore in the areas 76 and 77 (ophiolitic basalts and serpentinite, which would easily contain mineral such as nickel iron arsenides and typically contains veinlets of mixed sulphides such as pyrite, chalcopyrite and galena).

3.4 Summary of Archaeometric Investigation

The chemical/mineralogical groups described above do not coincide with the stratigraphic distinction of the samples; hence the process distinctions that can be drawn by the data seem to indicate the co-existence of different procedures at the site.

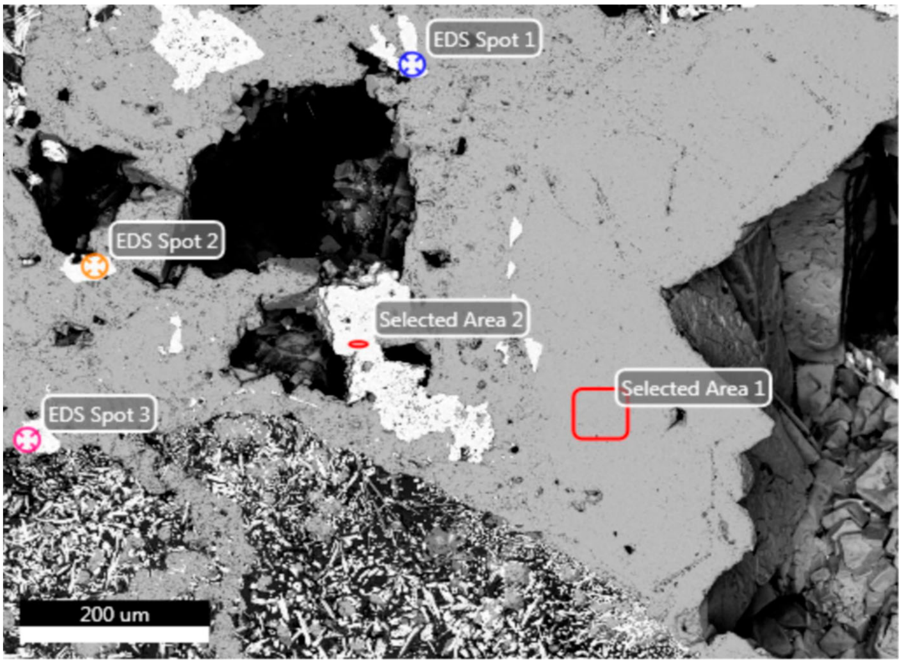

Figure 23. Sample 981, SEM backscattering image showing the copper matrix (grey) and segregation of lead (white) towards the porous area.

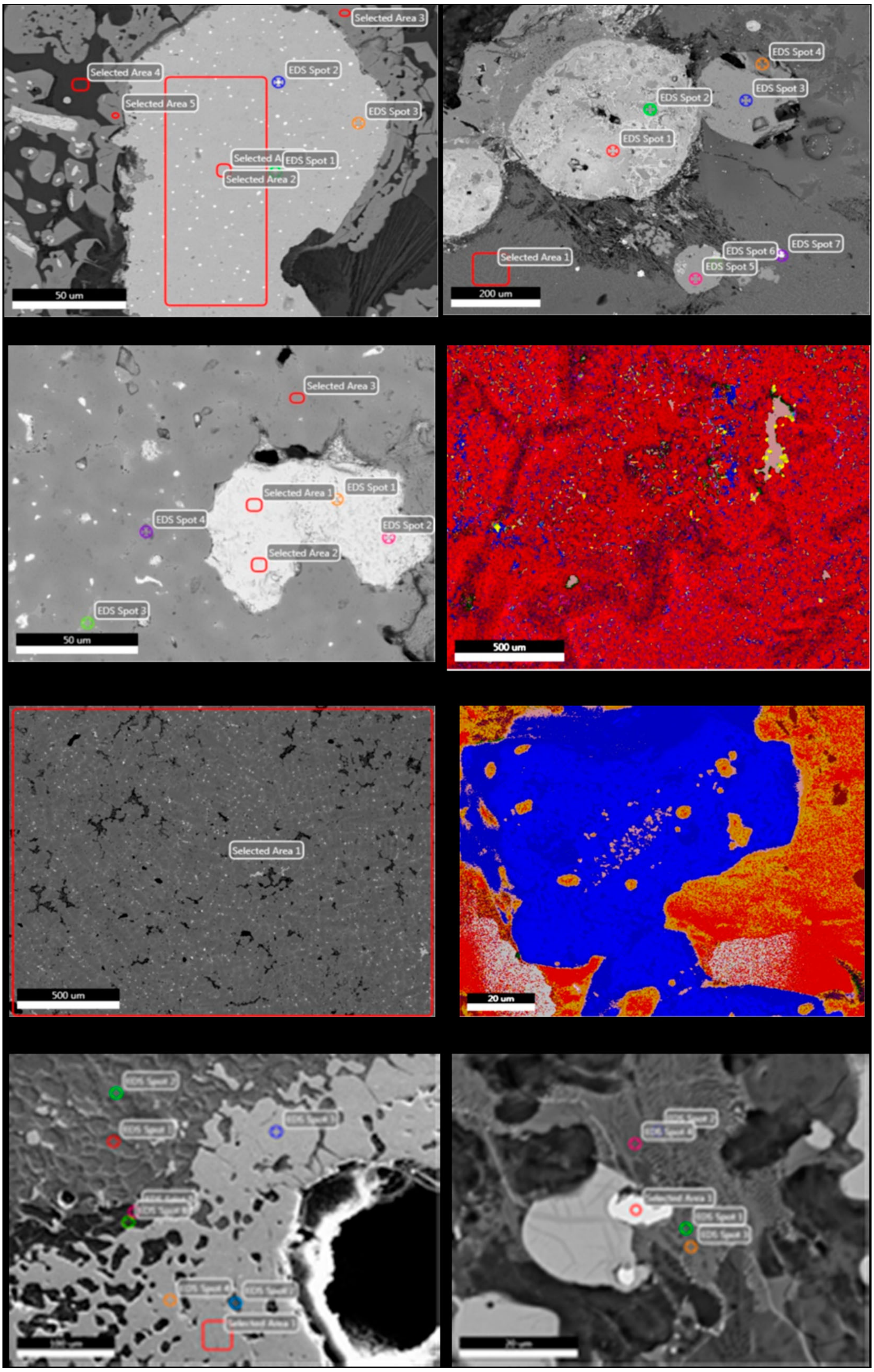

Figure 24. SEM images of the three main groups of bronzes.

The bronzes: recycling or alloying?

In the early Middle Ages the main process to produce bronze alloys is linked to the recycling of existing bronzes. Traces of recycling seem to be present particularly in sample 956-1, where a residual copper-enriched phase is associated with newly formed tin oxide pointing to the indication that tin oxide was "burnt out" of recycled bronze. However, at Grumentum the addition of metallic copper, can be observed in samples 956-2, where the source of tin can be identified as cassiterite, however it cannot be confirmed that all the tin in the process derived from cassiterite. Sample 958-2,

Table 1. Comparison between the composition of copper alloys detected at Grumentum and alloys from different sites and objects

SITE/BIBLIOGRAPHICAL REFERENCE	DESCRIPTION	Cu	Sn	Pb
Grumentum 956-1	Slag	91	8	0.5/1
Grumentum 956-3	Metal fragment	85.6	9.7	3.2
Grumentum 958-2	Slag	88.9-96.2	9.3-2.4	0.5-0.6
Grumentum 958-3	Metal fragment	93.8	5.8	0.4
Grumentum 958-4	Metal fragment	96.2	3.6	0.2
Riederer 2002	Handle 6799	84.2	12.2	3.20
Riederer 2002	Handle 10629	87.8	10.6	1.11
Riederer 2002	Casserole Ko N 8972	89.7	9.1	0.4
Riederer 2002	Casserole Ne D 75	89.5	9	0.8
Gliozzo, et al., 2010	Tham 9	85.1	11.5	2.6
Gliozzo, et al., 2010	Tham134	88.9	4.7	0.9
Zanda, 2002	Cornice 973	85.3	10.2	3.3
Zanda, 2002	Cornice 994a	87.8	10.1	0.7
Zanda, 2002	Cornice 994b	86.9	11	1.2
Zanda, 2002	Cavaliere 71992	83.4	10.8	3.2
Ponting, 2002	Strap plate	89.6	9.3	0.3
Hook & Craddock, 1996	Lamp 3541	86.1	10.9	1.0
Hook & Craddock, 1996	Lamp 3609	84.2	10.1	3.1
Hook & Craddock, 1996	Lamp 3615	87.1	10.6	1.5
Hook & Craddock, 1996	Lamp 3621	90.5	10.0	0.3
Hook & Craddock, 1996	Lamp 3636	84.5	10.9	3.5
Hook & Craddock, 1996	Lamp 3640	85.5	10	3.6
Hook & Craddock, 1996	Lamp 3725	89	10.2	1.9

on the other hand, also indicates the addition of tin directly in the mix because high tin prills are detected which cannot derive from the recycling of bronze, however there is no evidence to confirm if this tin was in metallic or mineral form. The varieties of the residues investigated seem to point out at the simultaneous use of different alloying processes within the same site:

- Use of scrap metal;
- Use of fresh metal;
- Direct use of cassiterite mineral.

The bronze composition (Figure 25)

The copper/tin and copper tin lead alloys indicate a high temperature of melting (~1000°).

It is well known that the choice of a particular kind of alloy was influenced by technological factors, cost and availability of raw materials, and, last but not least, by the kind of object to be produced.

In literature, published analyses of alloys have a strong bias towards artistic metalwork such as coins, statues and vessels. In the past few years, an important series of analyses has been performed on objects in daily use and military fittings (Hook and Craddock 1996; Dungworth 1997; Rieder 2002; Zanda 2002; Gliozzo et. al. 2010). The alloy's compositions measured in the metallurgical debris presented in this study are all represented in the literature and the composition shown by sample 956-3: Pb 3.2, Sn 9.7 and Cu 85.7 seems to be the most represented. The debris recovered at Grumentum might indicate the production of bronzes with 5 to 10% Sn and 0.5 to 3% lead; however, since the material analysed so far are very limited in number and do not include objects, the link between alloy and objects cannot be confirmed.

The presence of iron

Aside from the samples mentioned above, in particular 958-1 and 981, ca.1% Fe is also present in 958-2. In this sample the bronze newly formed droplets are associated with fayalite and magnetite similar to what can be seen in copper refining slags, potentially indicating a voluntary preferential oxidation of iron (refining) during the alloying process.

The presence of phosphorous

Samples 958-1 and 2 also show phosphorous concentrations.

Nickel and the indication of the mining area

Nickel and in particular nickel arsenides have a strong geological connotation. This element, mainly found in samples 958-1 and 981, is linked with arsenic as well as copper and iron. As sample 958-1 can be identified as an iron smithing slag and sample 981 as a bronze alloying slag the minor presence of these elements might start giving an indication of where the mineral for the initial smelting slags could derive. However, this can be only confirmed if smelting slags are recovered and identified at this site or in surrounding areas. The indications collected by the two metallurgical debris, seem to point towards an initial smelting of a mineralisation associated to mixed arsenides/sulphides

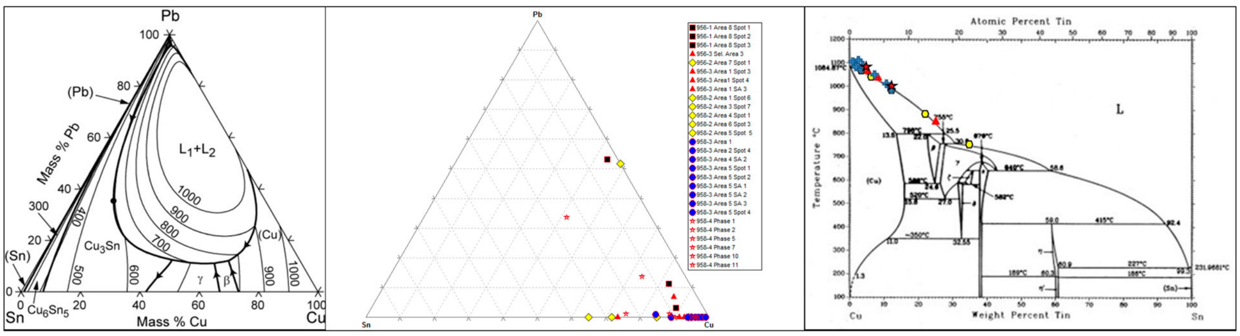

Figure 25. Ternary and binary diagrams showing the compositions of bronzes. Values are given in weight percents.

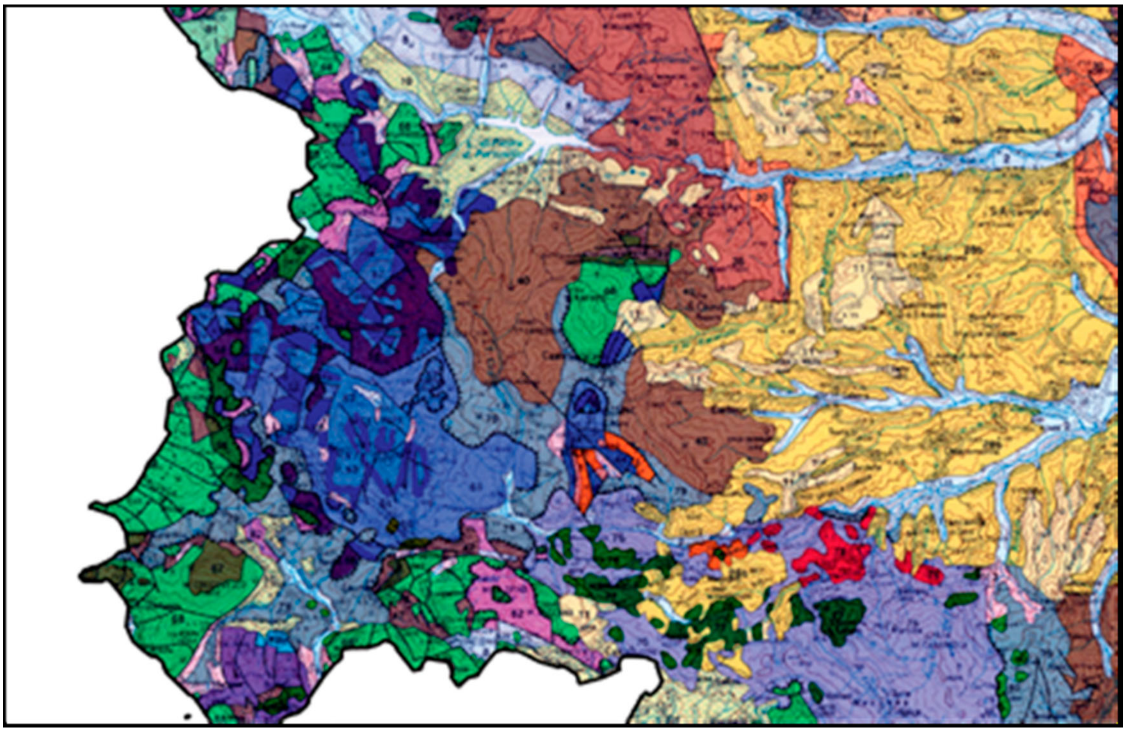

Figure 26. Geological map of Southern Apennine Mountains.

possibly smelted for copper and iron production in the area. Ophiolitic deposits identified North of Grumentum might be the source of such a mineralogical association, giving an indication of the use of local ore (Bonardi et al. 1988) (Figure 26). On the other hand, such deposits are known at the site of Acquaformosa and along the Grondo river valley in Calabria, which could be another possible source of mineral (Cuteri 2015). However, only a systematic investigation of smelting debris could confirm such hypothesis.

4.0 Conclusions

The analysed samples seem to indicate the simultaneous presence of recycling and melting of fresh metals for the alloying process with the aim of producing leaded bronze with a variety of compositions.

General considerations on the history of the city in this period (Jacobs and Lauritsen 2014), the information collected during our campaigns, including other previous and present excavations, and the fact that some bronze fittings belonging to the decoration of monumental buildings were found dismantled in a nearby area (probably for recycling) (Tagliente 2006), suggest that the activity of the furnaces might have been connected with the progressive disuse of the Forum area (a phenomenon recorded in many parts of Italy for this period). Nonetheless, it is clear that any major initiative on public buildings had to be agreed with the central authority, so that the spoliation and reuse would not be detrimental to the Treasury and urban decorum (La Salvia 2015). Recycling is a well-known phenomenon in the metallurgy of nearly all periods[1], even though it is always very difficult to estimate its dimensions and importance. In the case of Grumentum, the need to recover materials to create new objects is suggested by the small degree of specialization, with iron and bronze being both worked in the same area, seemingly simultaneously. Also, it is still uncertain what might have caused the shift from one type of productive structure (rectangular pits) to another (sub-circular hearths).

The productive activity could have served to the everyday life of the surviving part of the city, as well as for new buildings; possibly a Christian worship place detected at the end of the last campaign in 2014, which could not be investigated further (Mastrocinque 2014).

Moreover, the presence of bone objects (mainly hairpins) and animal bones with signs of processing suggests the possible existence of a cluster of workshops dedicated to diverse kind of productions, according to an association that has been found in numerous cases both in Rome (Palatine Hill, Basilica Hilariana, Forum of Caesar, Crypta Balbi) and outside (Aiano Torraccia di Chiusi, Spolverino)[2].

These findings brought to light that the workshop on the Forum can be interpreted as a coherent

[1]Pliny the Elder (NH 34, 97) mentions the use of *collectaneum aes* (recycled bronze) in the production of statuary already in the Ist century AD

[2]Also, it must be noted that a previous metalworking site, dating between the 1st and the 2nd century AD is testified in the Forum by the presence of a foundry located just opposite the temple, in the vicinity of the Basilica (Nava, 2004): the choice of this place might have been influenced by its vicinity to the Decumanus, the principal urban road which delimited the western side of the Forum square.

ensemble, corresponding to the destruction of a series of furnaces and to the dumping of their waste products, as the result of a specific kind of iron and copper alloy working. This is a preliminary report and aims to be the basis for further studies into the entire context, in order to insert it in the ampler perspective of metal production and reuse in Late Antiquity. The main process identified by this small assemblage of metallurgical debris consist in leaded bronze alloying. The raw material used for the alloying varies: fresh metal, scrap metal and minerals are used simultaneously to obtain leaded bronze with varying composition: Cu 85-95 Sn 3-10 Pb0.2-3.5. The scarcity of the analysed material and the absence of objects does not allow a link between alloy composition and specific use.

Therefore, we hope to be able to perform new analyses on other parts of the finds: for example, on the group of bronze residues probably put aside to be recycled, in order to determine the initial "raw" material for recycling. Analyses of prills trapped in the furnace lining could also provide an important indication on the process.

The evidence gathered so far, albeit preliminary, represents a further attestation of productive activity in a little-known period in the history of Grumentum itself and of Southern Italy.

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Disclosure statement

No potential conflict of interest was reported by the author (s).

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