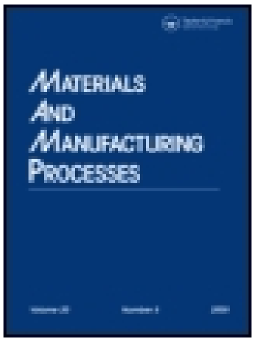


Materials and Manufacturing Processes

ISSN: 1042-6914 (Print) 1532-2475 (Online) Journal homepage: http://www.tandfonline.com/loi/lmmp20

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**To cite this article:** Giulia Bison, Lara Pozzan & Lorna Anguilano (2016): Metallurgical evidence from a late antique context in the Forum of Grumentum, Materials and Manufacturing Processes, DOI: 10.1080/10426914.2016.1232820

**To link to this article:** http://dx.doi.org/10.1080/10426914.2016.1232820

Accepted author version posted online: 19 Sep 2016.
Published online: 19 Sep 2016.

MATERIALS AND MANUFACTURING PROCESSES
http://dx.doi.org/10.1080/10426914.2016.1232820



# Metallurgical evidence from a late antique context in the Forum of Grumentum

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**ABSTRACT**

This article is a preliminary report on metallurgical activity detected in the Forum of the ancient city of Grumentum (Basilicata, Italy). In an area next to one of the most important temples of the square, a set of hearths belonging to a metallurgical plant was brought to light and investigated, together with a great quantity of metallurgical remains, a tuyère, and a fragment of what might be identified as an iron crucible: according to stratigraphic evidence and the preliminary data from the study of pottery sherds, this intense metallurgical activity seems to be dating to the Late Antique period. It is not clear yet if it has some relationship with the abandonment of the Forum itself.

**ARTICLE HISTORY**
Received 7 June 2016
Accepted 8 August 2016

**KEYWORDS**
Copper alloy; crucible; furnaces; hearths; iron; late antiquity; metallurgy; pits; processing; recycling; slags

## 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 center from its origins [1] (Fig. 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 the destruction in the Social War, it was rebuilt as a Roman colony, after the Laws of Caesar on colonization, around the year 59 BC [2]. 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 (probably devoted to the imperial cult), the Capitolium, and the Round Temple (Fig. 2). Grumentum remained a thriving center 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 reorganization of its urban spaces during the first half of the 4th century AD, the urban area gradually became depopulated only by the 6th century AD, and it was completely abandoned by the 9th century [3]. 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 archeological sequence ranging from the 2nd century BC to the present day [4]. 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 [5], while no traces of structures connected with metalworking could be 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 an intense metallurgical activity.

## Materials and methods

### *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 Pozzan between 2011 and 2013 (Fig. 3).

The workshop in which the metalworking activity took place is located beyond the southern side of the *Porticus* delimiting the Forum square: in its first arrangement, the workshop seems to be an open, probably roofless space, communicating with the colonnaded porch through an access. After the second half of the 1st century AD, the eastern part, a small porch open to the south, with L-shaped pillars made of stone and brick blocks, and brick columns, was built. Later, metallurgical activities developed in this area. Finally, the construction of some masonry structures determined the closure of the passage to the *porticus*, and consequently to the Forum, and the space was divided to form smaller rooms. The area was then 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 generically 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 (Fig. 4), not entirely explored yet, is characterized by three massive superimposed

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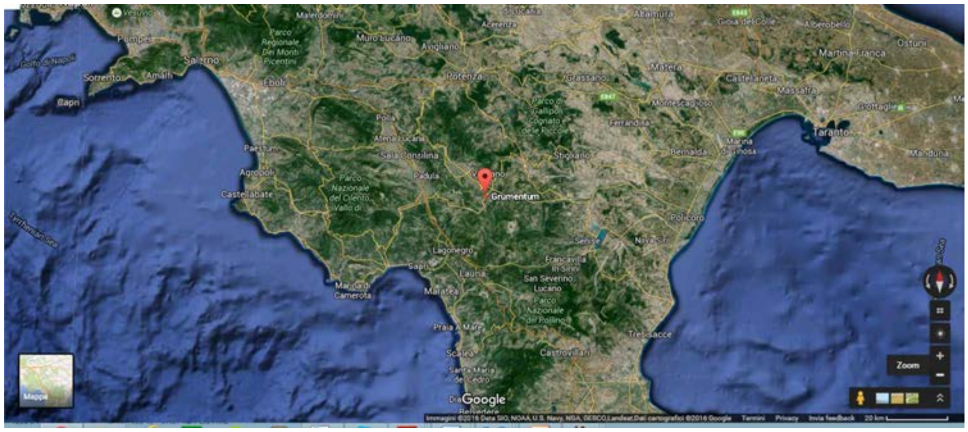


Figure 1. Localization of Grumentum in Southern Italy (via Google Maps).

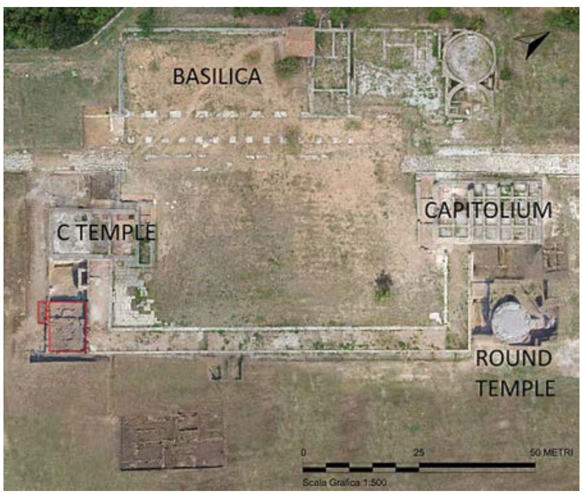


Figure 2. An overview of the Forum area: the workshop is highlighted in red.

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 clear yet, but they could have been used for the casting of bronze objects, probably by placing molds at the bottom and filling the pit with sand to hold the molds in place, as in metalworking sites such as those in Avenches [6], Verona [7], and Autun [8]. Slightly later, a second phase of activity took place directly above the obliterated pits (Fig. 5) and features a large number (at least 15) of overlapping, subcircular-shaped ground-level hearths, measuring between 80 cm and 2 m in diameter and 10–20 cm in depth. The context reflects an organization scheme that seems to have been common in many other metalworking sites dating from the end of the 1st century to the 7th century AD, such as those found in Milan [9], Rome, on the North-Eastern slopes of the Palatine hill [10], at Piazza Venezia [11], at the Athenaeum of Hadrian [12], and at Aiano Torraccia di Chiusi [13].

Three pits can be attributed to this phase: the westernmost has a sub-circular shape (90 cm × 100 cm, depth 25 cm),

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

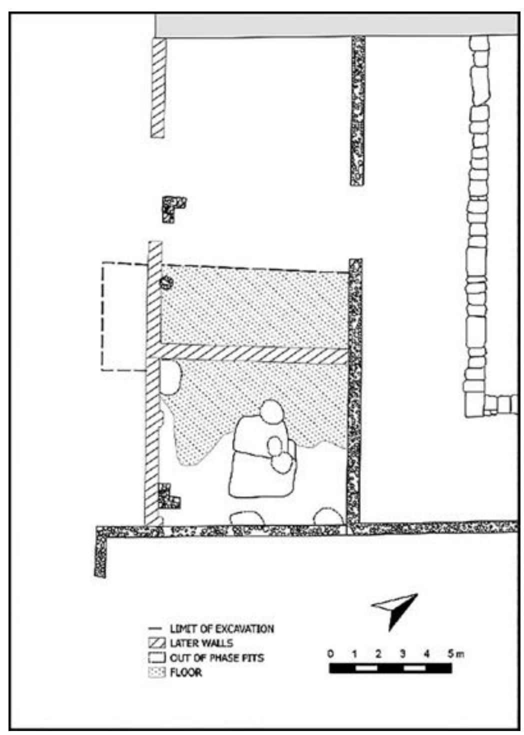


Figure 4. Plan of the structures of the first phase (drawing L. Pozzan).

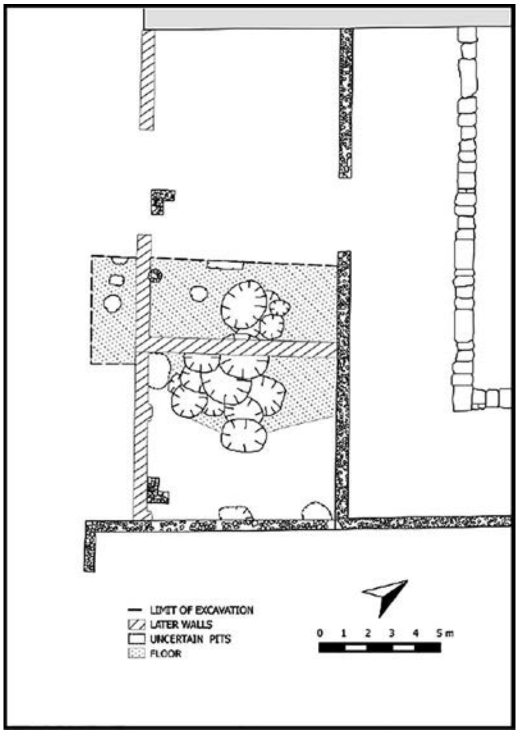


**Figure 5.** Plan of the structures of the second phase (drawing L. Pozzan).

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.

The attribution to this phase of three large circular pits (from 1 to 1.5 m, 40–45 cm deep) found along the perimeter of the workshop [14] is uncertain. These are two semicircular 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, in the South, there are three more 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-east 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, in activity 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 [15]. There seems to have been no specific place for dumping waste products, as all the debris was then used as filling and leveling material, until the metallurgical activity came to an end.

### *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 molds (Fig. 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 is also a copper alloy plate with a series of holes, most likely part of an unfinished object (Fig. 7).

Concerning the second phase and its hearths, the most important find is doubtless the fragment of a tuyère (Fig. 8). 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 (Fig. 9).

One last quite controversial find (Fig. 10) is a heavily corroded concave lump of iron. On its section, it is possible to distinguish a flat, rounded part with a low wall, similar to a shallow dish. Moreover, on the inner side of the flat part, there is a small drop of copper alloy. This object was interpreted as the bottom of an iron crucible, mainly on the basis of a comparison from Pompeii published by C. Giardino [16]. He mentions the existence of "large iron crucibles" containing residues of copper alloy stored in the National Archaeological Museum of Naples, as an evidence for the presence of bronze foundries in the city buried by the Vesuvius.

**Figure 6.** Mold fragments (photo G. Bison).


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

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

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

Serneels [17] also suggests the use of such objects (even though he could not find any) on a metalworking site in which many fragments of burnt clay were interpreted as protective coating for iron crucibles, applied to avoid a possible interaction between metal and alloy by high temperatures. In his opinion, iron crucibles could be linked to a specific amount of bronze to be melted for one operation. Obviously, this question remains open and calls out for a general revision: it needs a deeper study and analysis; nonetheless we can hypothesize that these tools, rare and peculiar as they must have been, were probably used only on specific occasions, maybe to melt a small quantity of copper alloy, probably intended for specific, possibly non-serial objects.

### *The slags*

A total of 192 pieces of metallurgical debris and remains were found: so far, it has only been possible to distinguish them by using morphometrical parameters [18]. Among them, 100 pieces of the so-called iron working slag, 89 remains from copper alloy working, and only 3 from lead melting could be recognized.

The iron working remains (Fig. 11) were roughly subdivided in three 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 (Fig. 12) 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 semi-corroded objects, which apparently were put aside for remelting.

Some debris originating from the alteration of the hearth wall lining caused by heat exposure was also identified (Fig. 13).

Before obliterating the rectangular pits, careful cleaning and maintenance left a very small quantity of bronze working residues, while at the moment of the final abandonment of the furnaces, a much larger amount of debris was 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. The hearths located on the eastern sector, on the other hand, show the opposite situation, with significantly more copper alloy residues than iron.

## Results and discussion

### *Archeometric investigation of metallurgical residues*

Eight samples of copper alloy production debris from the first phase were investigated using mineralogical and

**Figure 10.** Iron crucible? (photo G. Bison).

**Figure 11.** Iron slags (photo G. Bison).

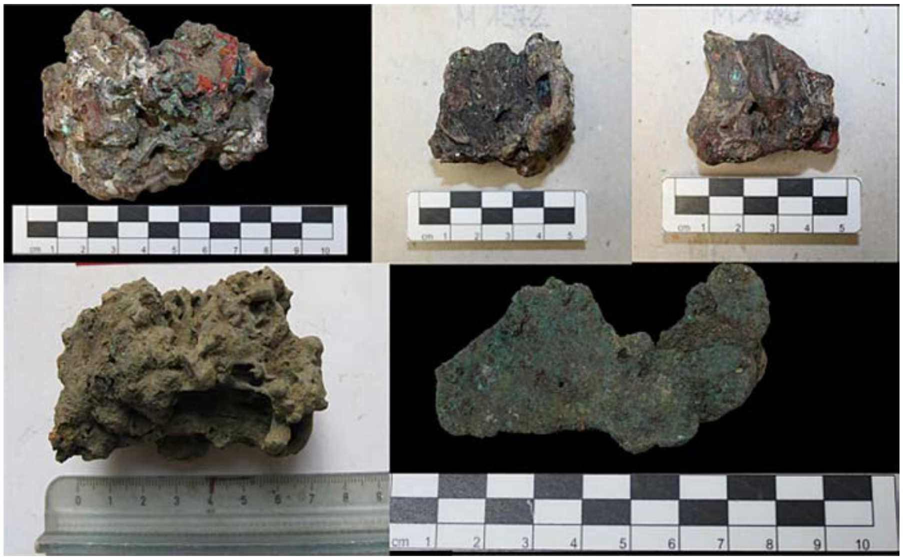

Figure 12. Copper alloy working remains (photo G. Bison).

chemical analytical techniques to evaluate the type of production they relate to and the raw materials used. All of them were part of the debris filling three smaller pits, cut over the rectangular pits. The samples were analyzed by x-ray fluorescence (Oxford ED 2000 with silver tube) and 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).

The samples were recovered from three different stratigraphic units (hereafter US), each one being the result of a different action, marked as 956, 958, and 981. All samples are identified as working slags from alloy production, and the following results aim at identifying the raw material and the final products related to the slags. No copper-based 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.

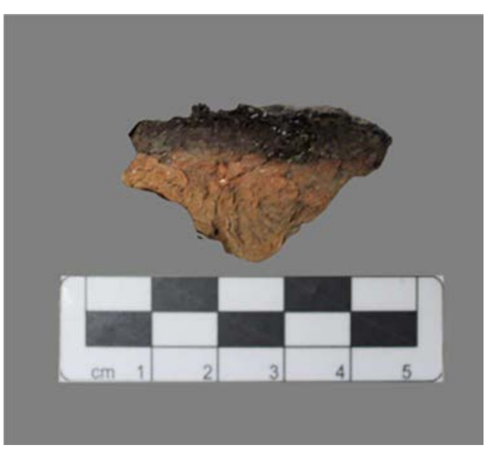

Figure 13. Scorched fragment of hearth wall lining (photo G. Bison).

Sample 956-1 is mainly composed of the mineral phases cassiterite and quartz. Elemental composition shows an important concentration of copper, lead, and iron in the bulk of the samples. Detailed investigation of the sample phases indicated tin oxide and tin metal, lead oxide, copper and copper oxide, and a matrix of calcium aluminum silicate. Several bronzes alloys were detected in the sample with the following compositions: $Cu_{42}Sn_3Pb_{51}$; $Cu_{81}Sn_6Pb_{11}$; $Cu_{87}Sn_8Pb_3$

Sample 956-2 is mainly composed of the mineral phases quartz and cassiterite (change of ratio between the phases compared to sample 956-1). The elemental composition shows also an important concentration of copper, lead, and iron (as in sample 956-1). A detailed investigation of the phases indicates the presence of copper and copper oxide (residual?), tin, tin oxide, and lead copper alloy. The silicatic matrix is calcium iron aluminosilicate ($XAlSi_2O_{10}$). Arsenic was detected in a tin oxide hopper crystal with minor copper. One bronze alloy with the composition $Cu_{63}$ $Sn_5Pb_5$ was detected.

Sample 956-3 is mainly composed of tin oxide and copper oxide. The elemental composition also shows a notable concentration of copper, lead, and iron (similarly to sample 956-1 and 956-2). Lead was detected through detailed phase analyses. Several bronze alloys were detected, three of them without lead—$Cu_{91}Sn_7$, $Cu_{72}Sn_{26}$, and $Cu_{84}Sn_8$—and one with lead $Cu_{88}Sn_{10}Pb_3(Fe_{0.2})$

Sample 958-1 is mainly composed of a mixture of iron oxides with different oxidation numbers and silicon oxide in the moganite polymorph. The elemental composition shows also an important concentration of iron, lead, and copper (ratios different from those of the previous samples). The detailed investigation of the phases shows the presence of calcium silicate (including minor phosphorous), nickel iron arsenide ($Ni_2FeAs$), and iron. No bronze alloys were detected in this sample.

Sample 958-2 is mainly composed of quartz and copper oxide. The elemental composition shows also an important concentration of copper, iron, calcium, and lead. A more detailed analysis of the phases indicate iron oxide, calcium iron silicate (including minor P), copper and copper chlorate, tin silicate, and tin oxide (hopper structure), associated with the previously mentioned calcium iron silicate with needle structure, a mixed cation aluminosilicate (XAlSi2O10), and the presence of both $Cu_2O_3$ and $CuO_2$ indicating quite high oxidating conditions; however, also CuO is present in the sample. Several bronze alloys, all without lead, were detected in this sample: Cu63Sn34, Cu58Sn23, Cu84Sn15(Fe1), Cu94Sn6, and Cu93Sn5(Fe2).

Sample 958-3 is mainly composed of quartz, cuprite, and copper chloride. Copper is also the main element detected in the sample. Detailed analyses of the phases indicated lead sulfate with a certain amount of copper, copper chloride, and lead/copper chloride (high lead ~80%). The morphology of the sulfatic phase seems to indicate a residual nature. Many bronze alloys were detected: Cu94Sn6Pb0.4, Cu89Sn11Pb04, Cu97Sn3Pb0.3(Fe0.2), Cu93Sn4(S < 1), Cu98Sn2, Cu97Sn2Pb0.3(Fe0.2), and Cu98.5Sn1(Fe0.3).

Sample 958-4 is mainly composed of quartz and cuprite. The elemental composition showed major concentration of copper, iron, calcium, and lead. Detailed analyses of the phases indicated chlorinated bronze, lead/copper, and tin/copper. Several bronze alloys were detected: Cu96Sn4, Cu90Sn10, Cu70Sn12Pb13, and Cu73Sn23Pb1.

Sample 981 is mainly composed of quartz, cassiterite, and tenorite. The elemental composition showed a major concentration of copper with minor lead and iron. Detailed analyses of the phases showed copper oxide, copper, and lead/copper sulfate. The morphology of the sulfatic phase seems to indicate a residual nature. On the right hand side of the sulfatic phase, triangular phases are visible. The morphology of this phase seems to suggest a newly formed lead sulfide. Nickel was detected in this sample associated with copper and iron. No bronze was detected in the analyzed area of this sample.

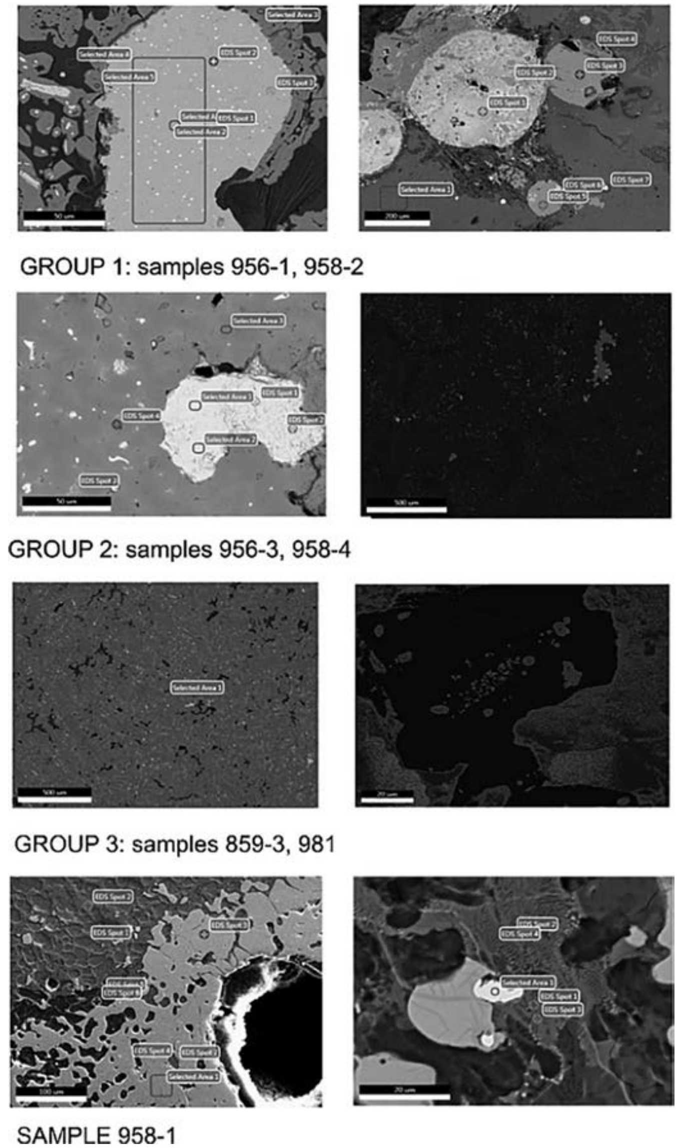


**Figure 14.** SEM images of the three main groups of bronzes.

## *Discussion*

The results indicate a possible distinction of the samples in three groups, plus one very dissimilar sample (Fig. 14).

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

Group 2 includes samples 956-3 and 958-4, i.e., more metallic samples mainly composed of copper, tin, and lead and the respective oxides. Bronzes alloys are still varied, but tend to have higher copper concentrations, from 70 to 96. In this group, both leaded and unleaded bronzes were detected. Sample 956-3 shows a minor concentration of Fe (0.2%).

Group 3 includes samples 958-3 and 981 which are characterized by the presence of lead/copper sulfate. In both samples, the morphology of the sulfate seems to be residual. The presence of sulfates and morphology linked to newly formed galena suggests that the sulfate is a product of oxidation of residual galena (or Pb/copper sulfidic phases) due to the alteration of the samples. This is confirmed by the strong presence of chlorine (visible in the constant alteration of the copper). The presence of newly formed lead sulfide grains seems to indicate the direct use of galena in the melt [20].

Sample 958-1 seems to be anomalous and shows a strong association with iron. However, this sample gives very important geological indication on the raw material used in the workshop, linked with strong nickel mineralization (also confirmed by the detection of nickel in sample 981, which still has signs of the original sulfidic ore). This sample also contains traces of phosphorous, which are found in other samples of the assemblage. Evaluation of the geological map of the area seems to indicate 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 contain veinlets of mixed sulfides such as pyrite, chalcopyrite, and galena).

## *Summary of archeometric 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 coexistence of different procedures at the site.

### 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; however, at Grumentum indications of addition of copper freshly smelted from the ore can be recognized in samples 958-3 and 981 and will be described below. The addition seems to derive from the use of fresh copper brought to the site from a smelting site which could be located elsewhere (see below for the discussion of the use of local ores), since no evidence of smelting was found on the site so far. It is also possible that galena was added directly to the melt during the alloying procedure. Indication of this procedure can be identified in the same samples 958-3 and 981. However, no indication on the use of tin or cassiterite can be determined. Sample 956-2 only shows indication of the use of tin, suggesting the possibility that tin was added as metal, directly to the newly produced alloy. High tin concentration in the newly formed prills is observed in samples 956-3, 958-2, and 958-4. This observation could confirm a further addition of tin to the recycling mixture [21].

### The bronze composition (Fig. 15)

The copper/tin and copper tin lead alloys indicate a high temperature of melting (~1000°) and a large variety of composition (tin concentrations between 1% and 15% in residual and uniformed newly formed large prills); however, much higher tin concentrations up to 35% were detected in small newly formed prills. The sample presenting bronze prills from US 958 seem to suggest a much more controlled composition (mainly around 3% Sn, see below).

In the literature, alloys composed of only copper and tin (in a 90% to 10% relationship) are a more expensive kind of alloy compared to the ternary composition which included lead and was used for other parts of the vessels, as for instance the handles [22]. The debris recovered at Grumentum might indicate the production of bronzes with 10% Sn; however, since the materials analyzed so far are only debris and not objects this cannot be confirmed.

Variability in tin content from 5 to 21% represents to some degree process variability, but most likely alloy composition was varied to suit the final object. While 5–10 wt% represented the "normal range," special objects may have been deliberately made using a higher tin content to achieve a more golden or silvery color [23]. This would mean that the two US might reflect two different types of final product requirements. However, since the difference in bronze composition is also associated to the presence or absence of sulfur/arsenic-bearing phases, we can infer that the bronze composition detected in the debris identify the raw materials, in US 956 a recycled mixture and in 958 a new alloying process. The difference in choice of raw materials can be due to a different final product requirements or a difference in material availability.

### The presence of sulfur and arsenides

Only three samples (981, 958-1, and 958-3) include sulfur or arsenic-bearing phases, which could indicate the use of newly reduced copper. The other samples present copper/tin/lead oxides and bronze phases, as well as chlorinated metals (indicating alteration). Of the three samples with indication of raw ore material, only sample 958-3 contained bronze. The bronze detected in this sample shows a very controlled composition with a maximum of 10% tin and Pb and Fe ~0.2/0.3%. The other two samples both contain nickel and iron.

As stated above, newly formed galena is detected in sample 981, indicating the possibility of direct use of galena to increase the lead concentration in the leaded bronzes. Addition of lead might be indicated also by the high concentration of lead in the leaded bronze prills of sample 956-1 (lead detected is around 50 wt%)

### 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.

### The presence of phosphorous

Samples 958-1 and 958-2 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 with copper and iron. This gives an indication of the mixed arsenides/sulfide ore possibly smelted for copper in the area. Ophiolitic deposits

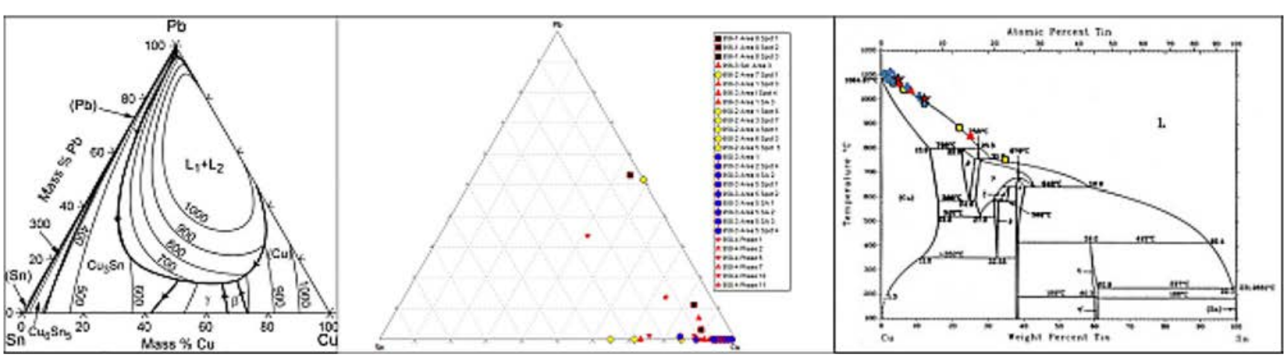


**Figure 15.** Ternary and binary diagrams showing the compositions of bronzes. Values are given in weight per cents.

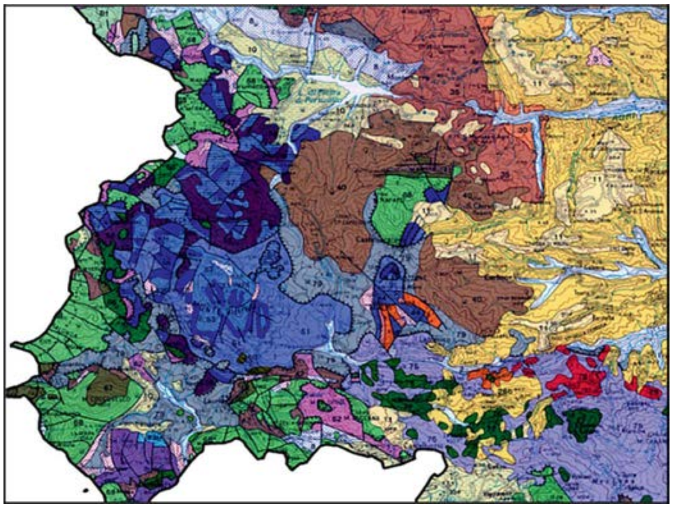

Figure 16. Geological map of Southern Apennine Mountains.

present in the North of Grumentum might be the source of such a mineralogical association, giving an indication of the use of local ore [24] (Fig. 16). 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 for mineral [25]

### *Recycling versus new production*

The large variety of bronze alloys in the samples from US 956 seems to indicate a diversified raw material composition. The absence of sulfur/arsenic and the large presence of oxides seem to indicate a remelting/recycling process. On the other side, the indication of residual elements, such as sulfur and arsenic, and the very controlled bronze composition of samples from US 958 and 981 seem to indicate a smelting production to obtain a more specific composition. The use of new raw material instead of recycling might indicate that the copper alloys used for recycling in town were running very low, or, more probably, due to the large settlement, a need for a specific alloy arose and new sources of materials were sought for and exploited.

General considerations on the history of the city in this period [26], together with the information collected during our campaigns and other previous and present excavations, and—last but not least—the fact that some bronze fittings belonging to the decoration of monumental buildings were found dismantled in a nearby area (probably for recycling) [27], suggest that the activity of the furnaces might have been connected with the progressive disuse of the Forum area. So far, there is no probative evidence allowing us to better identify the kind of production, which took place here.

Recycling is a well-known phenomenon in the metallurgy of nearly all periods, even though it is always very difficult to estimate its dimensions and importance. In the case of Grumentum, the small degree of specialization, with iron and bronze being both worked in the same area, as it seems, simultaneously, also suggests the need to recover materials to create new objects. It is not clear yet whether they were destined to the everyday life of the surviving part of the city or for new buildings—possibly a Christian worship place detected at the end of our last campaign in 2014 [28]. We also do not know what might have caused the shift from one type of productive structure (rectangular pits) to another (sub-circular hearths).

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 [29]. Moreover, the presence of bone objects (mainly hairpins, probably residual) and animal bones with signs of processing attests the possible existence of a cluster of workshops dedicated to diverse kind of productions: the choice of this place might have been suggested by its vicinity to the Decumanus, the principal urban road which delimited the western side of the Forum square.

## Conclusions

The finds brought to light in the workshop on the Forum can be interpreted as a coherent 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 of the whole context, in order to insert it in the more ample perspective of metal production and reuse in Late Antiquity.

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 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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