Early metallurgy in the central Mediterranean: Goals for the next decade

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ABSTRACT: The article's aim is to foster an interdisciplinary debate regarding the direction that archaeometallurgical studies in the central Mediterranean region, from the late Neolithic to the Early Bronze Age (c4500-1650 BC), ought to take in the next decade. It is argued that early metallurgical studies in the area have followed an idiosyncratic course due to the sway held on the discipline by Idealism, an influential philosophical movement that greatly hindered the development of science-based archaeology until the late 20th century. The last fifteen years, however, have witnessed an unprecedented if rather tumultuous expansion of metallurgical research, and important advances have been made in the chronology and chaîne opératoire of early metal technology and artefacts. Yet it is the author's contention that, in order to reap full benefits from the recent disciplinary growth, an explicit research agenda must be set. Above all, it is argued that the new agenda must be grounded in the cross-disciplinary examination of the materiality of metalwork, hitherto poorly explored in this region.

Introduction

In Italy the discipline of archaeometallurgy, and in particular the study of early metal-making and metal-using, followed a trajectory partly different from that witnessed in other Western countries. Its foundation, owing to the common positivist milieu that permeated much of Europe in the late 19th century, was marked by occasional chemical analyses of early copper alloys, which were conducted under the aegis of pioneering prehistorians including Pigorini, Castelfranco, Chierici and Colini (Pearce 1993, 51; Thornton and Giardino 2008, 386). As in the rest of Europe, these were followed in the early 20th century by the first research-oriented programmes, such as Mosso's (1906) investigation of the provenance of Mediterranean bronzes based on copper impurities.

However, this line of development was interrupted in the decades between the two world wars by the growing influence in Italy of Idealism, an anti-scientific ideology that dramatically changed the intellectual agenda of the country for the best part of the century. By and large, the shift was spearheaded by Italian philosopher and historian Benedetto Croce. Influenced by German idealists such as Hegel and Fichte, Croce regarded human knowledge as organised according to a value-laden hierarchy, which would mirror the asserted superiority of the human mind over matter (Guidi 1988, 78). This theoretical framework dictated the subordination of science to the arts and humanities, which in Croce's view were the only disciplines capable of addressing 'questions about the highest problems of the human spirit' (Croce 1950, 437 cited in Barbanera 1998, 124; author's translation).

Croce's thought, and its application to Italian education by the 'philosopher of Fascism', Giovanni Gentile, set the country on an idiosyncratic course that long outlived the fall of the fascist regime. The consequences were felt far and wide in post-war prehistoric studies, where the strict classical training of most researchers hindered any development of scientific archaeology (D'Agostino 1991; Peroni 1992). Therefore, when the discipline of archaeometallurgy hatched on the world stage in the

1960s (Craddock 1995, 6), this was little felt in Italian academia, where most prehistorians continued to concern themselves with the typological classification of objects (Thornton and Giardino 2008, 390). Given the prevailing cultural milieu, it is perhaps unsurprising that the scientific study of early Italian metals was frequently fostered by scholars and institutions based outside the country. To make the point, suffice it to mention the wide-ranging programmes of chemical analysis promoted by Otto and Witter (1952) and Junghans *et al* (1960; 1968; 1974), the characterisation of Early Bronze Age metalwork carried out by Barker and Slater (1971), and the reappraisal of the origins of Italian metallurgy undertaken by Renfrew and Whitehouse (1974).

The lack of an indigenous scholarly community may explain why the subject went through a long period of neglect from the late 1970s when foreign research dwindled. To some extent, interest in the subject was kept alive by sporadic collaborations between Italian archaeologists and materials scientists, mainly sought for the chemical characterisation of objects. The problem with such collaborations was that the scientists, who partook in the same idealistic milieu as the rest of the country, often perceived their role as subordinate to that of the archaeologists – a mere provision of raw data to feed the broad-brush interpretive pictures sketched by their colleagues (Thornton and Giardino 2008, 390-91). Hence, in the absence of any shared archaeometallurgical agenda, most of the analyses carried out in the 1980s and 1990s failed to address any real research problem, or else responded to purely scientific goals. For the same reason, Italian academia was exceptionally slow in developing fields of scientific enquiry other than metalwork characterisation.

There are, however, three notable exceptions to this trend:

- The eastern Alps, where cross-border cooperation ensured a continuation of the metallurgical enquiries during the 1980s and 1990s (*eg* Cierny *et al* 1995; Doonan *et al* 1996; Storti 1990-91),
- Sardinia, where the interdisciplinary work promoted by Fulvia Lo Schiavo provided a refreshing countertrend to the dismal continental panorama (*eg* Lo Schiavo 1989), and
- Corsica, where the research agenda, set by French-speaking archaeologists, was by definition immune from the Italian malaise (*eg* Camps 1988).

It is also worth mentioning the isolated case of *Sibrium*, an Italian archaeological journal that since its foundation promoted the scientific investigation of ancient technology (Pearce 1993, 52).

The tide started to turn in the late 1980s, when the first all-Italian conference on archaeometallurgy provided an opportunity for scientists and archaeologists to share their research (Antonacci Sanpaolo 1992). Undoubtedly the new climate fostered more robust investigations of later Bronze Age and Iron Age metal technology (*eg* Giardino 1995). However, little changed for another decade in the field of Copper Age and Early Bronze Age metallurgy, where some of the most thoughtful studies were still carried out by non-Italian researchers (*eg* Barfield 1996; Pearce 1993; Skeates 1993). It was only in the late 1990s that the new trend gained momentum, ushering in a new research season that continues to this day. The onset of the new era was aptly marked by the publication of the first Italian handbook of archaeometallurgy, which provided non-specialists with a compass to navigate through the subject (Giardino 1998).

Despite the significant if rather tumultuous developments witnessed in the last fifteen years (see below), the study of early central Mediterranean metallurgy still suffers from two drawbacks: firstly, a substantial gap of knowledge carried forward from the years of neglect, which is all the more apparent if we compare Italy with other major European countries, where uninterrupted research ensured the steady growth of the subject; secondly, a lack of debate regarding the subject's recent achievements and future developments, owing to the combined influence of its rapid expansion and the deep-seated aversion of Italian archaeologists to theoretical musing. While more research is doubtless needed to fill the knowledge gap, this must be guided by a broader reflection as to the direction that the subject is taking, and where it ought to be stirred. The aim of this paper is to contribute to such reflection. To this end, it offers an overview of the state of the discipline at the turn of the millennium, discusses the surge in archaeometallurgical studies in the last fifteen years and proposes a research agenda for the next decade, in the hope that this will promote cross-disciplinary debate amongst all students of central Mediterranean metallurgy. In conclusion, brief remarks are made concerning the social dynamics of prehistoric metal technology, an area where the cooperation between materials scientists and archaeologists can be most fruitful, and where a truly innovative agenda for the 21st century can arguably be grounded.

Once upon a time in Italy

The central Mediterranean region encompasses the Italian peninsula, its neighbouring islands and the eastern Adriatic coast. It is naturally bordered to the north by the Alpine chain, to the east by the Dinaric Alps, to

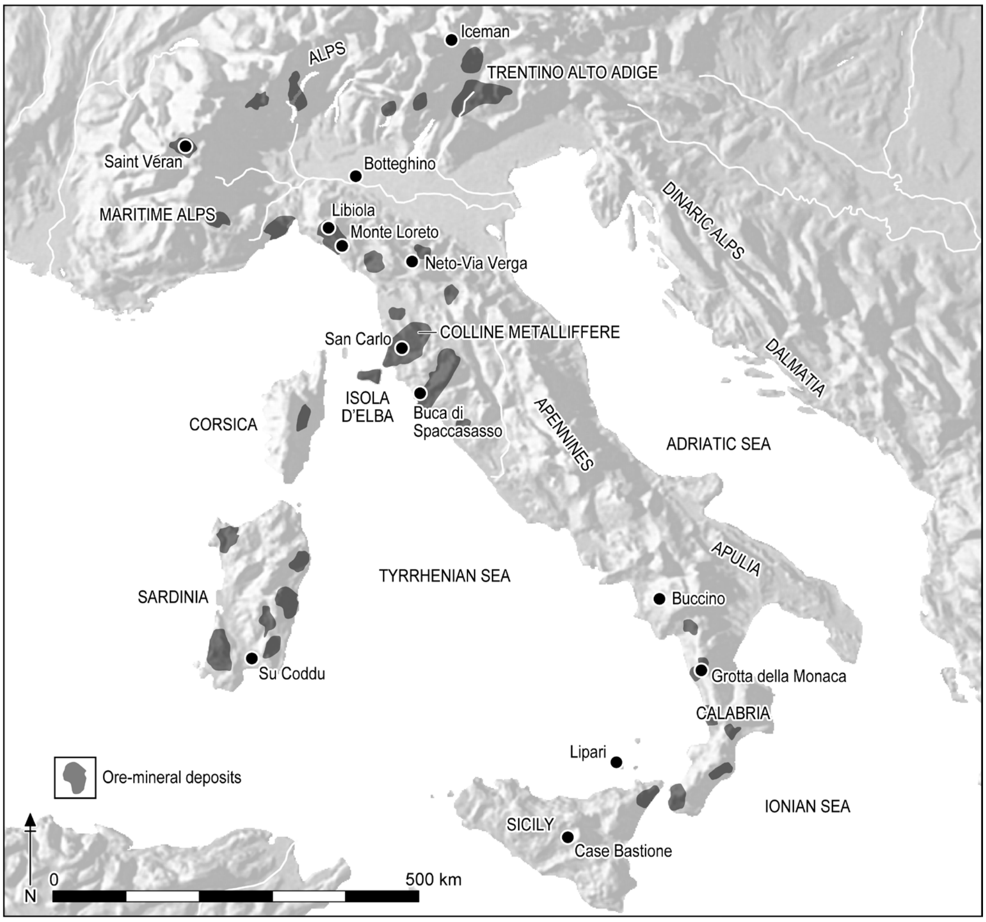


Figure 1: Early mining, smelting and metalworking sites mentioned in the text. The dark grey areas show the approximate location and size of the principal ore-mineral deposits found in the central Mediterranean region.

the west by an imaginary line linking the Maritime Alps to Corsica and Sardinia, and to the south by Sicily and the Maltese archipelago. Stretching from the heart of the Mediterranean to the fringes of central Europe and from the western Balkans to southern France, the Italian peninsula – the principal feature of this macro-region – is especially important from an archaeological perspective as it provided a natural channel of communication for peoples, ideas and goods in prehistory. The region is characterised by three major ore-mineral districts in the Alps (with a special focus in the eastern Alps), west-central Italy and Sardinia. It also features a number of relatively minor ore deposits, which are especially concentrated in the northern Apennines, the southern Apennines, north-east Sicily and Corsica (Cavinato 1964). In contrast, large swathes of the southern peninsula, most of Sicily, the Maltese archipelago, and the entire circum-Adriatic area are devoid of ore sources due to their different geology (Fig 1).

The ore deposits found throughout the region are extremely diverse. They comprise primary copper and iron-copper sulphides such as chalcopyrite and bornite; fahlores of the tetrahedrite-tennantite family which may be rich in arsenic, antimony and silver; and galena, which is occasionally argentiferous (especially in Sardinia). Secondary deposits resulting from the weathering of primary ores are also encountered, particularly south of the Alps. These include malachite and azurite as well as native copper, the latter reportedly found in significant amounts until the 20th century (Baumgarten *et al* 1998; Carobbi and Rodolico 1976; Giardino 2009-12; Pearce 2007, ch4; Valera and Valera 2005). Stibnite and cassiterite are also found in Tuscany. Whereas the former was almost certainly smelted in the Copper Age for metallic antimony, prehistoric exploitation of the latter is most uncertain (Giardino *et al* 2011; Penhallurick 1986, 80-82; Tanelli 1989).

Traditionally, knowledge of extractive metallurgy is thought to have spread during the Copper Age (or Eneolithic) after isolated experiments in the late/final Neolithic (Table 1). The Copper Age witnessed the development of the first metallurgical 'cultures' including Remedello in northern Italy, Rinaldone in the west-central peninsula and Gaudo in the south-west, while Laterza – the first copper-using 'culture' found in Adriatic Italy – would have emerged later (Guidi and Piperno 1992, *passim*; Giardino 2000). However, the region's eastern and western fringes were long thought

Table 1: Absolute chronology from the Middle Neolithic to the Early Bronze Age in the central Mediterranean region.

Archaeological phase	Absolute chronology
Middle Neolithic	*c*5000-4500 cal BC
Late/Final Neolithic	*c*4500-3600 cal BC
Copper Age	*c*3600-2200 cal BC
Early Bronze Age	*c*2200-1650 cal BC

to provide earlier evidence of the new craft. In Sardinia and Corsica the extractive technology of copper and silver would have appeared in the late/final Neolithic (Camps 1988; Lo Schiavo 1989), while eastern Adriatic metallurgy would have begun even earlier thanks to the region's connections with the central Balkans (Cazzella 1994; Žeravica 1993). By contrast, the southernmost part of the central Mediterranean including Sicily and Malta attracted little scrutiny due to the insubstantial metalwork predating the Bronze Age (Giardino 1997).

Early seriation work

Throughout the 1980s and 1990s, research often focused on the evidence and chronology of early metal working and using. Scholarly attention was mostly devoted to the construction of fine-grained seriation sequences for early axes, daggers, and halberds. In line with the theoretical approaches prevailing at the time, it was implicitly assumed that evolutionary criteria could provide guidance as to the chronology of objects. For example, it was presumed that the 'more complex' axes with raised margins would have been later than the 'more primitive' flat axes, and that daggers and halberds with loosely defined 'elaborate' features would have developed out of earlier, simpler types (Carancini 1993). However, very few attempts were made to validate the seriation sequences through independent means of dating (Fig 2).

Due to the speculative nature of the typological work, the evidence was pulled in two opposite directions. On the one hand, following an early proposal by Peroni (1971), a number of influential Italian prehistorians divided early metalwork into two clear-cut horizons, each marked by specific types of objects. Based on evolutionary criteria and a number of questionable comparanda, they assigned the first horizon to the advanced Copper Age (*c*3000-2200 BC), and the second to the initial Early Bronze Age (*c*2200-2000/1800 BC) (Bianco Peroni 1994; Carancini 1993; 2001; Peroni 1989; 1996). To account for the objects occasionally found at earlier sites, they posited that the first horizon would have been preceded by a lengthy phase with insubstantial 'incipient metallurgy' based on imports from the northern Alps or the Balkans (Carancini 2001, 236). A similar if slightly backdated chronology limited to northern Italy was proposed by De Marinis (1992; 1997). On the other hand, a number of British scholars claimed that the origins of Italian metallurgy would be firmly rooted in the local Neolithic. In particular, it was debated whether a handful of archaic copper axes from northern Italy could be dated to as early a period as the middle Neolithic (*c*.5000-4500 BC; Barfield 1966; 1996; Skeates 1993). Although the problem was largely left unresolved, the controversy provided an opportunity to challenge the prevalent orthodoxy, and fed the debate with a growing amount of data concerning the earliest stages of Italian metallurgy.

Interestingly, the typological dispute continued well into the 2000s despite the changing research climate and the growing number of radiocarbon dates available for the Italian Copper Age (*eg* Carancini 2006; Pearce 2007, ch3). The most stimulating proposal was put forward by De Marinis (2006). Focusing on the abundant

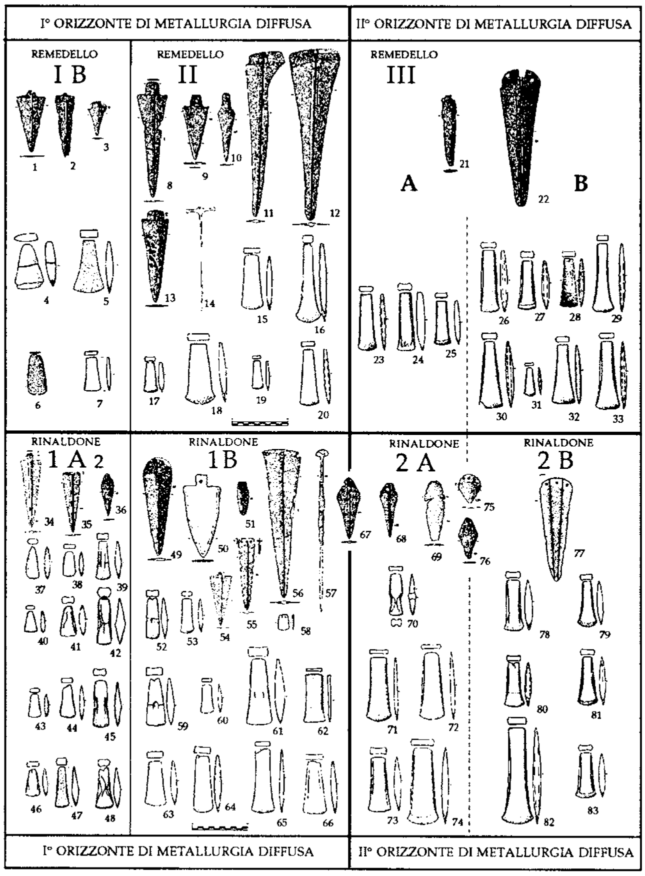


Figure 2: Dating metalwork in the 'good old days'. Recent applications of radiocarbon dating have dramatically disproved traditional chrono-typological sequences like this one, based on evolutionary criteria and incorrect applications of the seriation method (after Carancini 2001).

'Rinaldone' metalwork from central Italy, he suggested that differences in chemical composition could help to solve the chronological conundrum. In particular, he argued that daggers and halberds made from arsenical copper – the product of an allegedly simpler technology – would belong to an earlier horizon datable to the late 4th and early 3rd millennia BC, whilst objects made from arsenical-antimonial copper would have been typical of a more developed technological stage, which he assigned to the mid/late 3rd millennium BC.

Despite some criticism (Barfield 1996; Conti *et al* 1996), a consensus of sorts eventually coalesced around the proposal put forward by Peroni and followers (Heyd 2013; Pare 2000; Strahm 2005; 2007; Strahm and Hauptmann 2009). Their research, later integrated with De Marinis's (2006) higher chronology, generated an orthodox view that can be summarised as follows:

- Italian metallurgy would have developed significantly later than in neighbouring regions including the northern Alps, the eastern Adriatic and Sardinia,
- early artefacts could typologically (and perhaps technologically) be divided into two clear-cut horizons, the first covering the mid/late Copper Age (*c*3200-2500 BC), and the second the late Copper Age and initial Early Bronze Age (*c*2500-2000/1800 BC)
- tin-bronze technology would have only appeared in the advanced Early Bronze Age, *c*2000/1800 BC.

As we shall see below, later research dramatically disproved all elements of this scenario.

The chaîne opératoire of early metal making and using

Since most of the attention was focussed on the heated seriation dispute, comparatively little effort was made to advance knowledge and understanding of the *chaîne opératoire* of early metal making and using (Ottaway 2001). Research in this area was often led by scientists and the data were slow to trickle down into archaeological circles (but see Pearce 1993; Pearce and Oddone 1993). Knowledge of prehistoric mining mostly dated back to the early 20th century, when the industrial exploitation of Italian ore deposits had led to the discovery of ancient shafts and galleries (Cocchi Genick and Grifoni Cremonesi 1989, 213-22; Giardino 2009-12, 15-18; Pearce 2007, 62-66). Interestingly, some of the early reports referred to the working of cinnabar, a brick-red mercury compound sourced as a pigment in the late Neolithic and Copper Age (Mochi 1915). This provided much-needed clues to the great antiquity of some of the workings, and offered stimulating if little explored insights into the early procurement of mineral substances for reasons other than extractive metallurgy.

Figure 3: Selection of spoon-shaped crucibles from Terrina IV, Corsica; the butt of the left-hand crucible is approximately 30mm across (after Camps 1988).

The picture was not much brighter with regard to early reduction technology, with the notable exception of the eastern Alps and Corsica (Camps 1988; Cierny *et al* 1998). This was not due to lack of evidence – for considerable amounts of processed ore, slag, spoon-shaped crucibles, tuyères, moulds and perhaps even an ore roasting installation had been brought to light all over the central Mediterranean region (Fedeli 1995; Lo Schiavo 1989; Sarti 1998; Villari 1981) – but to the unfavourable research climate, which did not compel archaeologists to scientifically examine the metallurgical residues (Fig 3).

The problem is best exemplified by an alleged final Neolithic crucible from Lipari, a small island off the coast of Sicily (Bernabò Brea and Cavalier 1980, 490). Due to its location and great antiquity, the find was hailed the ultimate proof of the introduction of extractive metallurgy from the eastern Mediterranean. As it chimed with well-rehearsed academic readings, this hypothesis entered unquestioned into the literature, and soon achieved the status of a factual reality (*eg* Pessina and Tiné 2008, 134). However, the greenish substance adhering to the Lipari crucible was never analysed for its chemical composition and micro-structure, and we are today no more certain about its metallurgical nature than its finders were in the 1970s. No wonder that so much of the later evidence was left unexplored if this was the treatment afforded to one of the earliest metallurgical finds from the central Mediterranean.

With regard to provenance studies, most of the isotopic work of the 1980s and 1990s was carried out on Sardinia, where however it concentrated on later oxhide ingots (see Gale and Stos-Gale 2000; Hauptmann 2009 for review). Indeed, some of the Italian copper deposits were investigated for their lead-isotope fingerprint (Stos-Gale *et al* 1995; Lattanzi *et al* 1992), but this did not trigger any meaningful provenance research, which would obviously have necessitated the isotopic characterisation of the objects. In contrast, knowledge of metalwork composition was generally good owing to the wide-ranging programmes of chemical analysis carried out in the previous decades (Barker and Slater 1971; Junghans *et al* 1960; 1968; 1974; Otto and Witter 1952). However, this was often limited to bulk composition, and did not normally encompass metals other than copper.

The final stages of the *chaîne opératoire* of metal making were also investigated to some extent. Due to their small sample size, however, these investigations did not lead to broader inferences about the nature of early metalworking. For example, early use of native copper was suggested by the compositional and micro-structural analysis of late Neolithic awls and axes (Campana and Franceschi 1997; Matteoli and Storti 1982). As it supported time-honoured opinions regarding the evolution of copper technology, the problem was not further investigated despite the early warnings about the difficulty of identifying native copper in ancient artefacts (Maddin *et al* 1980; but see Pernicka *et al* 1997 for a different opinion). Likewise, inconsistent smithing patterns emerging from the metallographic examination of a halberd and two daggers from Buccino, a Copper Age cemetery in southern Italy, did not prompt further enquiries into the problem (Avery *et al* 1973).

As is apparent from this overview, the long-standing legacy of Idealism and the 'years of neglect' caused by the dwindling of non-Italian research generated a substantial knowledge lag in central Mediterranean archaeometallurgy. This was about to change dramatically at the turn of the new millennium, when renewed interest in the subject, which had slowly been gathering pace since the early 1990s, newly put the discipline in the limelight.

The great leap forward: 1998-2013

The last fifteen years have witnessed a significant surge in archaeometallurgical studies throughout the entire central Mediterranean region. Major results have been achieved in all areas of the *chaîne opératoire* of early metal production and use, and significant gains have also been made regarding the chronology of early metal objects. Moreover, this period saw the establishment of a more systematic dialogue between archaeologists and materials scientists, promoted by the Associazione Italiana di Metallurgia through the conference series 'Archaeometallurgy in Europe' (2003; 2007).

Disentangling the chronological knot: mission accomplished?

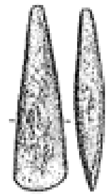
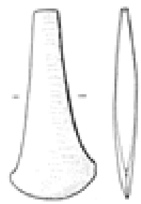
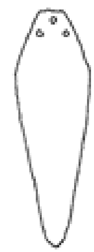
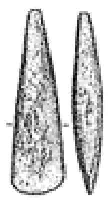
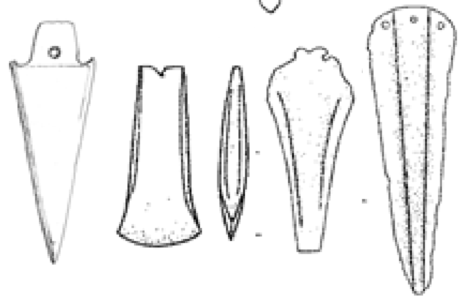
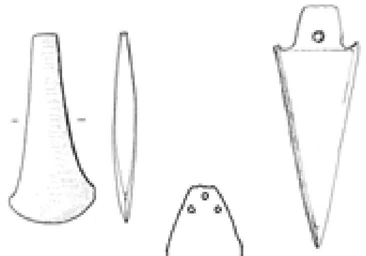
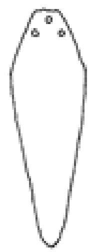
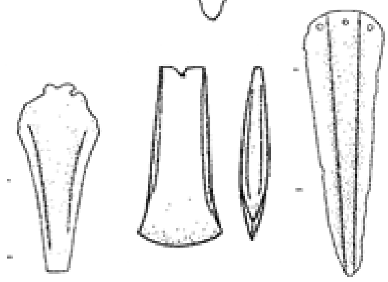
Recent research has strengthened early claims about the antiquity and importance of Neolithic metallurgy. One of the most important discoveries was made at Botteghino, a settlement site in northern Italy. Here, two copper awls, possible slag and a potsherd with adhering copper lumps were unearthed in a stratified context dated to 4501-4365 cal BC (Hd-25298, 5619±25 BP; Mazzieri and Dal Santo 2007). If confirmed analytically, this evidence will testify to the near-simultaneous inception of copper smelting north and south of the Alps in the mid/late 5th millennium BC (Dolfini 2013). Importantly, it also tallies with the growing number of objects (including axes) known from late 5th and early 4th millennia BC sites south of the Alps (Dolfini 2013; in press; Klassen 2010; Pearce, 2007: 42-46; Usai 2005). Overall, these findings bear witness to the Neolithic inception of Italian and Sardinian metallurgy, thus disproving previous assumptions regarding its later commencement.

Furthermore, the systematic application of radiocarbon dating has provided an opportunity to reappraise the chronology of Copper Age metal objects from Rinaldone, Gaudo and Laterza 'cultures' of central and southern Italy, yielding results that can probably be extended to northern Italian Remedello sites (Dolfini 2010; Dolfini *et al* 2011; Manfredini *et al* 2009, 161-67; Passariello *et al* 2010; Petitti *et al* 2011). Significantly, the new dates have knocked down the house of cards painstakingly built by the typologists of old. Objects that were previously thought to be Late Copper Age turned out to be Final Neolithic, and objects traditionally assigned to the Early Bronze Age were newly dated to the Early Copper Age (Table 2). It was also shown that arsenical-antimonial alloys, previously thought to belong to a late metallurgical phase (De Marinis 2006), had been mastered from an early stage together with pure and arsenical copper. Overall, radiocarbon dating has proved that

- the polymetallic metallurgy of copper, lead/silver and antimony began in earnest in the early Copper Age (3600-3300 BC), probably after an intensification phase in the final Neolithic (3800-3600 BC),
- several types of axe, dagger and halberd were cast in bivalve moulds for much of the Copper Age using a number of alloys including pure, arsenical and arsenical-antimonial copper, and
- there are no indications of the alleged occurrence of two clear-cut horizons based on the typology or manufacturing technology of objects (Dolfini 2010).

One of the most substantial achievements of the recent

Table 2: Synoptic table showing the chronological revolution brought about by the radiocarbon dating of early central Mediterranean metalwork.

Phase	Dates cal BC	Old typological chronology	New radiocarbon chronology
Late Neolithic	4500-3800		
Final Neolithic	3800-3600		
Early Copper Age	3600-3300		
Middle Copper Age	3300-2700		
Late Copper Age	2700-2200		
Early Bronze Age phase 1	2200-2000		
Early Bronze Age phase 2	2000-1800		

Note: All Copper Age objects in the table have been precision-dated by radiocarbon except for the two Neolithic axes whose chronology is based on solid stratigraphic and archaeological grounds.

dating programmes consists of shifting back by several hundred years the entire chronological sequence of early central Mediterranean metallurgy. A probable if yet unproven consequence of the new chronology is that the beginnings of tin-bronze production should be pushed back from *c*2000/1800 BC to 2200/2000 BC, in the initial early Bronze Age. Notably, this would agree with similar evidence from central and western Europe (Ottaway and Roberts 2008; Pare 2000), and would seem all the more plausible in the light of undoubted if sporadic Copper Age experiments with tin-bronze alloys (Bulgarelli and Giumlia-Mair 2008; Campana *et al* 1996). Be that as it may, the recent re-dating of early metal production has already proved its worth by prompting a reconsideration of the reception, elaboration and further transmission of metal technology by Italian prehistoric communities (Dolfini 2013).

Early mining research

A number of early mining sites have been investigated in the 2000s. Amongst the most important are Libiola and Monte Loreto, two chalcopyrite mines dating from mid-4th to mid-3rd millennium BC. At Monte Loreto, in particular, the findings include artificial galleries backfilled in prehistory (Fig 4), evidence of fire-setting, extensive dumps of graded mining debris (informative of in situ beneficiation) and basalt hammerstones sourced some miles away from the site (Maggi and Pearce 2005; Pearce 2007, 62-70).

Moreover, extensive evidence of 3rd millennium BC bornite exploitation was brought to light at Saint Véran, a high-altitude mining and smelting site in the western Alps (Bourgarit *et al* 2008). At the opposite end of the peninsula, early procurement of brightly coloured copper and iron compounds was revealed at Grotta della Monaca, but it is unclear whether the minerals were sourced for their metal content or to make pigments (Geniola *et al* 2006; Larocca 2005). Prehistoric ore mining is also suggested by scatters of hammerstones from a number of sites recently discovered in central and southern Italy, although their chronology is mostly unclear (Aranguren and Sozzi 2006; Giardino and Steiniger 2011; Novellis and Veneziano 2011).

Finally, a cinnabar quarry was excavated at Buca di Spaccasasso, a Copper Age burial cave in southern Tuscany (Cavanna and Pellegrini 2007). This is the first time that prehistoric mining is found to be associated with burial in the Italian peninsula, although

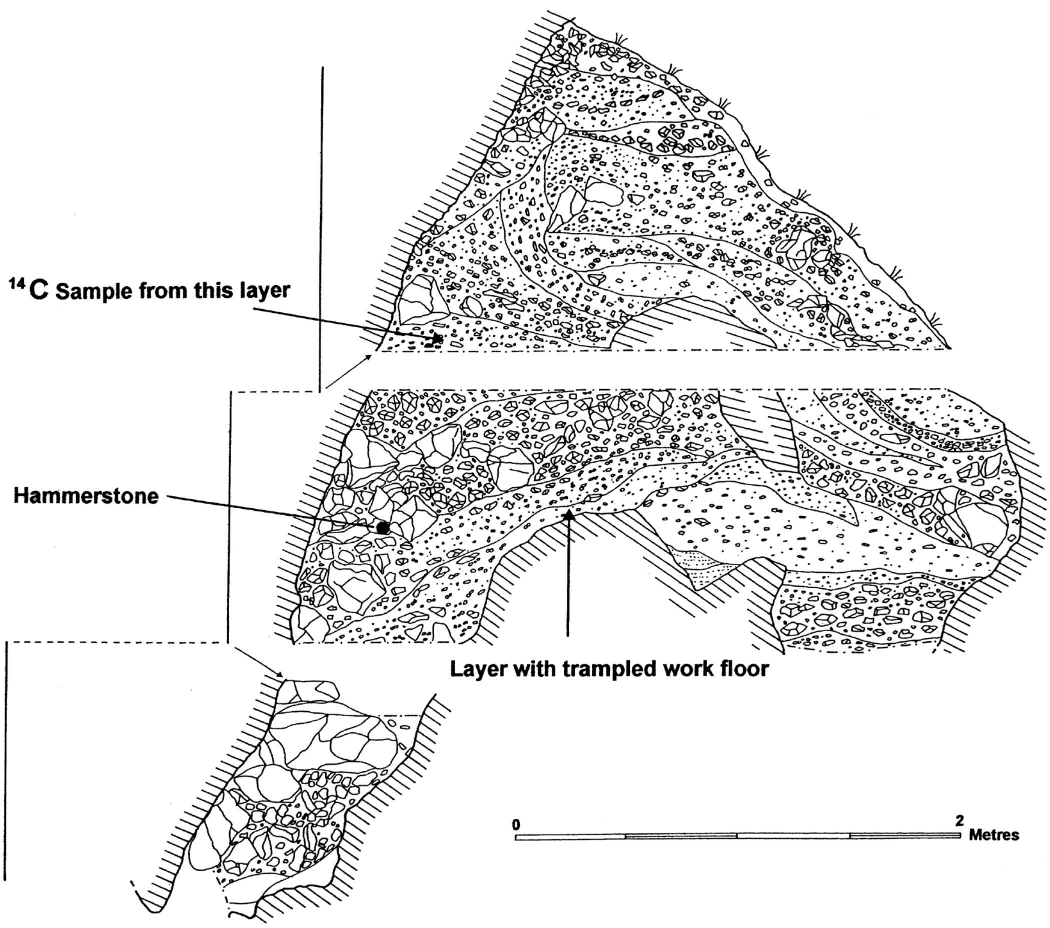


Figure 4: Section across a prehistoric gallery at Monte Loreto, a 4th millennium BC copper mine in Liguria, NW Italy (after Maggi and Pearce 2005).

the phenomenon is not unknown in other regions of Mediterranean Europe (*eg* Blas Cortina 2005). Burial was practised at early metallurgical sites in the eastern Alps, where however it is associated with smelting, not mining (Pedrotti 2001; Perini 2001). It is also noteworthy that in southern Tuscany cinnabar deposits are often mingled with stibnite ores. This might suggest that metallic antimony, used in the Copper Age to make ornaments, was independently discovered in this area because of the late Neolithic procurement of cinnabar for funerary purposes.

Investigating early smelting and metalworking

Research into early smelting was significantly advanced in the same time period. Not unexpectedly, the eastern Alps drew most of the scrutiny due to the abundant evidence and long-standing interest in the subject. It was ascertained that early slags would mostly fall within the parameters of so-called Chalcolithic smelting technology (Bourgarit 2007). This is characterised by the widespread use of open reactors and by the lack of fluxing, which both led to the incomplete reduction of the copper ore under partly oxidising conditions. Incomplete ore reduction can be appreciated in the coarse, viscous, and highly heterogeneous slags found at many an Alpine site, which had to be crushed to recover the entrapped copper prills (Artioli 2011; Dolfini 2014).

However, unbroken slag 'cakes' recovered from certain late 3rd and early 2nd millennium BC sites (Fig 5) testify to more efficient smelting conditions in which copper-rich matte would have developed (Artioli *et al* 2007). Strikingly, analysis revealed that early Alpine smiths were occasionally able to master even more sophisticated reduction processes which one would not expect to encounter until the advanced Bronze Age. In particular, skilful control of all smelting parameters including furnace temperature and atmosphere are indicated by the thick fayalitic slags found at Saint Véran, which however were still broken to recover entrapped metallic copper (Bourgarit *et al* 2008). It was also ascertained that from the Copper Age Alpine metalworkers were capable of reducing copper and iron-copper sulphides including chalcopyrite, bornite and fahlores (Anguilano *et al* 2002; Artioli *et al* 2007; Bourgarit *et al* 2008; D'Amico *et al* 1998). This disproves earlier beliefs in the sole utilisation of copper oxides prior to the Bronze Age, and provides further support to similar evidence from the northern Alps (Höppner *et al* 2005).

Figure 5: Sub-circular slag 'cake' from La Vela di Valbusa in the eastern Alps.

South of the Alps, early smelting residues were solely afforded preliminary analyses, but the results were nevertheless of interest. In Tuscany, Copper Age usage of sulphidic ores as well as mastery of the matte-smelting process was suggested for San Carlo, a now-destroyed domestic site (Artioli *et al* 2007; Fedeli 1995); in Sardinia, unsubstantiated claims for Neolithic copper and silver smelting were rebutted by analysis of slag from Su Coddu, which seem to point towards ceramic pyrotechnology (Manunza *et al* 2005-06; Melis 2005); and in Sicily the recent discovery of shallow fired-clay basins at Case Bastione, a late 3rd millennium BC domestic site, might provide the earliest evidence of copper smelting on the island (Giannitrapani and Iannì 2011). However, preliminary analysis does not confirm the metallurgical nature of the finds, and ongoing research is trying to clarify the problem (Lorna Anguilano, pers comm).

Knowledge of early casting and smithing has also progressed appreciably in the last decade. Early proposals concerning the late Neolithic working of native copper have been strengthened by new metallographic analysis (Artioli *et al* 2003a; Giumlia-Mair 2005, 276). However, this showed that Neolithic copper technology was much more sophisticated than previously supposed. For example, features were highlighted on two archaic Italian axes which can only be explained by vertical casting in two-piece moulds (Giardino 2009-12). This supports recent suggestions regarding the early use of bivalve moulds in Italy, and also inferences about the frequency of sand casting in European prehistory (Artioli *et al* 2003a, 18; Dolfini 2011; in press; Kienlin 2010, 71; Ottaway and Seibel 1998; Pallecchi *et al* 2002; Wang and Ottaway 2004). Taken together, these data disprove long-held assumptions concerning the gradual evolution of copper technology from 'simple' monovalve to 'more advanced' bivalve casting.

Early metalwork forging was also elucidated. In particular, neutron diffraction analysis revealed somewhat inconsistent smithing patterns in a sample of twenty Copper Age axes from the southern Alps (Artioli 2007). Notwithstanding the different sample size, this study provided a comparison with contemporary north-Alpine flat axes of the Altheim type (Kienlin 2010, Ch. 4; Kienlin *et al* 2006). Whereas most of the north-Alpine implements had been subjected to high-temperature annealing followed by a final cycle of work-hardening, the south-Alpine tools generally underwent partial re-crystallisation and moderate volume reduction, and were often left in the soft annealed state. This shows that while early north-Alpine smiths were perfectly aware of the mechanical properties of the copper metal and exploited them to increase tool hardness, the metalworkers operating south of the Alps were either unaware or not interested in enhancing tool functionality via work-hardening, and seem to have limited their action to shaping the axes after casting or use.

Finally, the use life of early metal tools and weapons was scrutinised by means of use-wear analysis (Fig 6). This revealed an array of use marks, which contradicted prior proposals concerning the non-functional nature of Copper Age metalwork (Dolfini 2011). Interestingly, the point was independently confirmed by the examination of bone artefacts from east-central Italy, which showed manufacturing marks left on the bone by metal blades (Cristiani and Alhaique 2005).

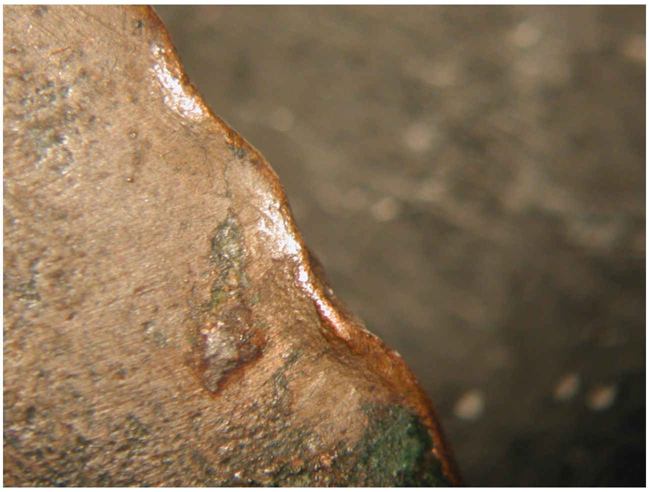


Figure 6: Detail of the cutting edge of an early copper axe-head from the province of Siena, central Italy. The use marks visible on the cutting edge indicate that the tool was used in prehistory for tasks including tree-felling and wood-working.

Setting the agenda for the next decade

It has been argued that in the last fifteen years significant achievements have been made in early metallurgical studies. All stages of the *chaîne opératoire* of metal making and using have been explored as rarely ever before, and Copper Age metal artefacts have now been dated by radiocarbon. Perhaps more importantly, this period saw the inauguration of systematic research partnerships between archaeologists and materials scientists. This brought about an unprecedented disciplinary *floruit*, which promises to yield enduring research advances for the foreseeable future.

However, to ensure steady growth for years to come, the future work needs to be channelled into an explicit research agenda which can only grow out of an interdisciplinary debate in which both archaeologists and scientists must participate. The agenda should concentrate energy and resources on the most pressing problems, ground the new data in a broader, shared research platform and bring the Central Mediterranean to a par with other regions of the Old World, where studies of early metallurgy have been much less affected by the vagaries of changing philosophical paradigms. Thus the agenda proposed here will focus on the chronology and *chaîne opératoire* of early metal making and using.

In pursuit of a science-based classification of artefacts

The last few years have seen the crumbling of time-honoured chrono-typological sequences, whose limits ranged from the incorrect application of artefact seriation methods to the use of over-detailed classification schemes, unsupported by independent means of dating (Barfield 1996; Conti *et al* 1996; Dolfini 2010). Arguably, these were just manifestations of two underlying intellectual flaws: an unshakable belief in the gradual evolution of technology and material culture and the assumption, derived from pottery studies, that metal objects could not significantly change their shape during their life-cycles. Both postulations are incorrect and this needs to be recognised if we are to make any progress in metalwork classification.

The first flaw has long been deconstructed in the archaeology, anthropology and history of technology (Basalla 1988; Pfaffenberger 1992). Quite apart from the difficulties that one would experience in defining concepts such as 'simple' and 'complex' in human technology, the limitations of evolutionary thinking become readily apparent when considering how varying and context-specific the social conceptualisations of material culture are. In particular, artefact variability depends on social dynamics such as conscious and unconscious technological choice (Lemonnier 1986; 1993), agency and identity (Dobres 2000; Ehrhardt 2005), the adoption and adaptation of new materials and objects (Schaniel 1988; Sørensen 1989), and numerous other factors including the mode of technology transfer and the nature of the interaction between practitioners (Ingold 1997; Killick 2004; Wenger 1999). Importantly, technology is as much characterised by devolution and loss of technical knowledge as it is by innovation and growth (Edgerton 2008, 207-210; Pfaffenberger 1992). There is no denying that technological progress frequently occurs in human history. However, this is neither necessarily gradual nor need it follow a linear, unwavering trajectory. This is the case in early European metallurgy, where instances of rapid, punctuated development were often followed by long-drawn phases of technological stasis or outright devolution, the most notable being the eastern European 'hiatus' of the 4th millennium BC (Chernykh 1992; Taylor 1999).

The second flaw was first pointed out by Barfield (1996, 65), who noted that the very characteristics of early metal technology including the widespread use of sand moulds and the production of fairly unstandardised cast blanks (especially for axe-heads) led to a degree of artefact variability that is normally not encountered in the Bronze Age. Significantly, his observations were later vindicated by scientific analysis and experiments, which showed that early metal axes were often hammered into shape after casting. This would have caused modifications of the original cast blanks to a degree that may vary considerably throughout the record (Artioli 2007; Budd and Ottaway 1995; Kienlin 2010, ch4; Kienlin *et al* 2006). This evidence provides a compelling argument against over-detailed classification schemes (*eg* Carancini 1993) which would risk grouping together unlike tools made the same by hammering, or separating similar cast blanks that had different post-casting histories.

The lesson to learn here is that good working knowledge of prehistoric metal technology as well as careful examination of the objects – if possible enhanced by microscopy (Dolfini 2011) – must be indispensable prerequisites for any meaningful classification work. Where possible, these should be complemented by microstructural analysis of the objects in order to highlight their post-casting treatment, and the results should be formalised through metrical or computer-processed approaches (Aspes and Fasani 1992; Read 2007). Scientific examination should concentrate in particular on those

Figure 7: The Iceman's copper axe-head. The dating and analysis of this tool disproved long-held beliefs concerning the evolution of axe margins and other technological traits. Length 95mm.

features for which observation alone may not be sufficient, as is the case with axe margins. The problem with visually identifying margin hammering first arose with the Iceman, whose copper axe was initially believed to be early Bronze Age on account of its slightly raised flanges (Spindler cited in Skeates 1993, 24; Fig 7). Of course the claim was soon disproved by radiocarbon dating, which assigned the Iceman and his equipment to the late 4th millennium BC, and was further denied by neutron diffraction analysis, which showed that the little margins of the Iceman's axe had been outlined in the mould (Artioli *et al* 2003b; Spindler 1994). This tale reminds us that it may be unwise to consider purely technological traits as chronologically relevant, and that integrated archaeological-scientific approaches are often needed to understand how a certain object came to obtain its final shape. On both counts, extant classification schemes ought to be revised.

A final point to be made concerns the usefulness of artefact seriation in the radiocarbon era. Surely, one may argue, it would seem futile to labour over abstract classification schemes when metalwork could be precisely dated through associated organic material. Sensible though such a statement may first seem, the state of the central Mediterranean evidence suggests that there are undoubted gains to be made by theoretically-renewed typological exercises. All over the region, the vast majority of early metalwork consists of non-datable stray and hoard finds, or else of objects from multi-phase burial chambers that were often used for hundreds of years. The implication is that radiocarbon dating alone will never be able to provide us with fine-grained chronologies for a reasonably large number of objects. Artefact classification will therefore remain for years to come an indispensable tool for assigning specific types of object to a certain time period. The problem is particularly acute for the Italian Copper Age, where most metal tools and weapons now float within a 1400 year period *c*3600-2200 BC.

Expanding chaîne opératoire studies

Recent investigations of the *chaîne opératoire* of metal procurement, smelting and working have brought to light important data, but also exposed problems and gaps in knowledge that warrant targeted research. For example, the discovery of prehistoric mining sites suggests that, amazingly, some early workings have survived thousands of years of large-scale ore exploitation. One would presume that important discoveries can still be made by surveying the central Mediterranean mining districts, especially in those areas that escaped modern open-cast mining due to the limited commercial value of the ore (Giardino and Steiniger 2011). Arguably, this should be just the first step of any meaningful mining research agenda, for an array of problems including overground and underground mining technology, ore beneficiation processes and the social organisation of mining communities need to be addressed once the prehistoric workings have been unearthed (Ambert *et al* 2009; Craddock 1995, ch2; Galiberti 2005; Krause 2009; Stöllner 2014; Timberlake 2003; 2007; Wager 2009).

One of the most interesting problems concerns the nature of the ore sourced at the beginning of extractive metallurgy, and how this changed following improvements in smelting practices. The latest research has ascertained that 3rd millennium BC Alpine (and possibly Tuscan) smiths were able to reduce iron-copper compounds such as chalcopyrite and bornite (Artioli *et al* 2003a; 2007; Bourgarit *et al* 2008). However, it is still unclear when exactly this was achieved, and if iron-copper ores were routinely smelted south of the Alps prior to the Bronze Age. Indeed, both the chemical composition of early Italian objects and the first mining/smelting practices in other regions of Europe point towards widespread oxide- and fahlore-based metallurgy (Angelini *et al* 2011; Bourgarit and Mille 2005; O'Brien 2004; Rovira 2005, and see other papers in this volume). Not only does the problem bear important implications for our understanding of prehistoric extractive technology; it is also central to social enquiries into the ancient conceptualisation of ore-mineral substances (Bray 2012; Dolfini 2012; Radivojević *et al* 2013). Overall, the problem can best be addressed through a combination of targeted mining research, chemical characterisation of slag and finished objects, lead isotope analysis, and perhaps copper isotope analysis, which seems to be capable of discriminating between primary and secondary ores from the same deposits (Artioli *et al* this volume; Klein *et al* 2004; 2010).

The issue is inextricably linked with early smelting technology, which is still insufficiently known south of the Alps. Here, the research agenda seems straightforward: more analysis is to be done on early slag and crucibles, and the analytical data are to be verified through experimental smelting. Importantly, the experiments should now move from chalcopyrite and oxidic ores, which have hitherto drawn most of the attention, to fahlores, galena and stibnite, which were presumably sourced for copper, lead/silver and antimony respectively (Giardino *et al* 2011; O'Brien 2004, 532). Moreover, long-awaited archaeological data regarding early smelting sites such as San Carlo (Fedeli 1995) and Neto-via Verga (Sarti 1998) ought to be put in the public domain without any further ado (Fig 8). From a technological perspective, these should allow us to clarify whether metallic copper was obtained through the direct co-smelting of mixed charges, the indirect reduction of sulphidic ores after dead-roasting, an early form of matte-smelting (possibly documented at San Carlo: Artioli *et al* 2007), or a combination of the three (Bourgarit 2007; Lechtman and

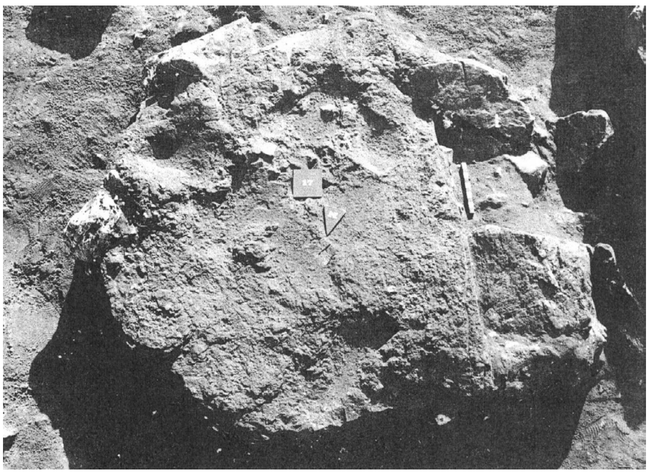


Figure 8: Circular hearth from San Carlo, a Copper Age metallurgical site in Tuscany, central Italy. It has been suggested that this open-air installation was used for roasting and perhaps smelting the copper ore, but final archaeological and analytical reports concerning this evidence are still awaited (after Fedeli 1995; the scale shown in the photograph is 10cm long).

Klein 1999; Rostoker *et al* 1989). From an archaeological viewpoint, they will undoubtedly fertilise the debate concerning the social context of early copper smelting (Dolfini 2014).

Another strand of research awaiting further development is metalwork provenance. Following in the footsteps of Sardinian and Alpine isotopic studies (see above), research should now be extended to the Italian peninsula, focusing on major Tuscan deposits as well as the relatively minor outcrops lying in the northern Apennines, southern Apennines, Sicily and Corsica. Interestingly, a novel approach has been pioneered in Alpine provenance studies, which integrates geo-chemical tracing with copper and lead isotope characterisation of ores and artefacts; the method has yielded most promising results, but proved rather time-consuming (Artioli *et al* 2008, and see Artioli *et al* this volume). Whether or not this approach will be extended to the rest of the central Mediterranean region, the importance of science-based provenance studies cannot be underestimated. Now that the heated debate concerning the reliability of lead isotope analysis has largely subsided, the technique can profitably be employed (alone or in combination with geochemical tracers) to match extensive Neolithic obsidian and greenstone exchange studies, and perhaps to challenge unspoken assumptions regarding the long-range circulation of early metalwork throughout the central Mediterranean region.

Needless to say, future research must not shy away from the final stages of the *chaîne opératoire* of metal making and using. A number of unresolved problems still haunt our understanding of early casting and smithing practices, and how these changed over both space and time. Interestingly, non-destructive and micro-destructive analytical techniques have recently been tested, which circumvent the sampling restrictions widespread at Italian museums. For example, metallography has been pioneered on micro-samples, and non-destructive neutron diffraction analysis has been successfully applied to early metalwork (Angelini *et al* 2009; Artioli 2007). Furthermore, use-wear analysis has shown that meaningful insights can be gained of the life-cycle of copper-based tools and weapons (Dolfini 2011). As with all new methods, the priorities for the next decade lie in expanding the number of objects analysed, refining the analytical protocols, and establishing the degree to which different techniques are comparable. This is the case, for example, with neutron diffraction versus metallography as well as traditional micro-wear analysis versus metalwork wear studies. Finally, the old databases of bulk artefact composition can be given a new lease of life by fast-developing research into metal re-use and recycling (Bray 2012; Bray and Pollard 2012; Perucchetti *et al* 2012). This is an area where firm and reasonably fine-grained artefact seriation sequences are sorely needed if we are to make any meaningful progress.

Conclusions: towards social archaeometallurgy

Arguably, the greatest challenge for the years ahead lies in crossing the disciplinary gulf that still partly separates archaeologists from materials scientists. Based on recent theoretical developments in British archaeology I would argue that a much-needed rapprochement between the two could be brought about by a common interest in the materiality of early metals. First conceptualised in the mid-1990s (Gosden 1994), the notion of materiality has found fertile ground in artefact studies in the last two decades, and it is now increasingly applied to archaeometallurgical investigations, where the sister notion of 'metalleity' has recently been introduced (Bray 2012). Despite some criticism, the concept is heuristically useful in that it encompasses both physical and social components of the artefacts and technological processes. This is especially conducive to research collaborations between scientists, who favour 'hard' objective methods of artefact analysis, and archaeologists, who often concern themselves with 'soft' and more subjective interpretive approaches (Jones 2004 and responses in *Archaeometry* 47(1), 2005; see also Ingold 2007 and responses; Thornton and Roberts 2014). I would venture so far as to contend that a truly original research agenda for early central Mediterranean metallurgy could only stem from the reflexive cross-examination of both material and social qualities of the artefacts and technological processes. Its ultimate aim must be what I would call *social archaeometallurgy*, a disciplinary strand in which the latest techniques of archaeometric investigation are deployed to address a broad spectrum of problems rooted in contemporary social theory.

Archaeological studies of early central Mediterranean metallurgy have long been dominated by an overarching narrative, loosely based upon Childean premises, which postulated the prime role of metals in triggering social ranking. In this vein, the finding of modest metal assemblages in graves was often sufficient to trigger accounts of the exceptional prestige of the individuals being buried, and to surmise the emergence of a 'Big Man' society in Copper Age Italy. However, in much of Europe early metals do not seem to have fundamentally altered the tribal structure of prehistoric communities, where by and large affiliations continued to be based on kinship, gender and age (Kienlin 2013; Kienlin and Stöllner 2009; Roberts 2009; 2011). Despite the dearth of targeted research on the problem, it is suggested here that this reading would nicely fit most of the central Mediterranean evidence, where a dispassionate examination will reveal little in terms of structured social inequality. The spurious link between early metalwork and social complexity is perhaps best exemplified by Temple Period Malta, where impressive collective undertakings were carried out in the complete absence of metalwork to act as a power catalyst.

Freed from worn-out preoccupations regarding prestige, ranking and societal inequality, future research could more profitably concentrate on the materiality of early metals, and how the new objects contributed to redefining people's ideas of being in the world. In many respects, the path has already been trodden in world metallurgical studies, where for example integrated scientific and anthropological studies of colour and artefact composition have shed light on the ancient conceptualisation of metallic substances (Fang and McDonnell 2011; Hosler 1994; 1995; Lahiri 1995; Lechtman 1988; 1996a). Likewise, interdisciplinary investigations of skeumorphism and cross-craftsmanship have yielded tremendous insights into prehistoric technology, and pioneering explorations of the sensory aspects of metal casting, working and using are now paving the way for the more formalised, science-enhanced approaches advocated in these pages (Frieman 2012; Keates 2002; Lechtman 1996b; Kuijpers 2013). Far from being exhaustive, these examples show what could be done to advance subject knowledge in central Mediterranean metallurgy. On a broader level, they also indicate the direction that the subject must take in order to arrive at a meaningful, interdisciplinary, and above all novel research agenda for the 21st century.

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