Metallurgical Networks and Technological Choice: 
understanding early metal in Western Europe

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Introduction

This paper analyses how metal objects and metal production practices in Western Europe during the fourth and third millennia BC were transmitted in space and time and explores how prehistoric communities shaped this process. This encompasses the earliest copper, arsenical copper, gold, silver and lead through to the earliest copper-tin objects in Spain, France, Holland, Belgium, Britain and Ireland. The ideas, techniques and projects that shaped past scholarship are assessed in order to explore an approach that goes beyond the limitations of current perspectives. The paper then evaluates the earliest dates for metal objects and production practices within the broader European context as well as how the transmission of metal could have occurred by exploring the presence of earlier comparable or transferable knowledge, expertise or material practices. The broader spatial and temporal patterning in the available choices and identifiable actions that influence the production, circulation and deposition of metal objects in Western Europe are then examined. It can be shown that, despite the necessary existence of metallurgical networks and centres enabling production, metal objects very much reflected the specific and changing demands of communities involved.
Chronologies, Migrations and Technologies

Debates concerning the potential antiquity of metal in Western Europe crystallised during the mid-late 19th century due to the excavation of prehistoric sites containing copper objects, most famously at Los Millares, southeast Spain (Siret & Siret 1887) as well as stone tools associated with “primitive mines” in copper ore deposits (Domergue 1987). The perceived importance of the earliest metals led to the proposal of a ‘Copper’, ‘Eneolithic’ or ‘Chalcolithic’ Age (e.g. Much 1885; Cartailhac 1886; Lichardus & Echt 1991) distinct from Ages of Stone and Bronze that achieved gradual acceptance throughout much of continental Europe though its existence is still disputed in Britain, Ireland, the Low Countries and Scandinavia. The appearance of copper objects in the archaeological record therefore heralded a perceived significant transition from the Stone Age to the Metal Ages. This technological and chronological shift encouraged broader societal changes in the minds of many scholars. Consequently, the explanations proposed for the appearance of metal objects and mines invariably involved technologically superior colonisers – migrating peoples from the east who settled in western lands bringing their culture, which included knowledge of metallurgy, with them. Metal was understood throughout all antiquarian scholarship to have been inherently desirable due to being a self evidently more advanced and superior technology.

The significant increase in the quantity of archaeological excavations and material culture studies during the early to mid 20th century had little influence on these migration-orientated interpretations. Theories therefore remained firmly orientated towards the influx of metallurgically-skilled outsiders who exploited the local ore sources. These ranged from the migration or invasion of ‘peoples’ to the more
piecemeal and gradual diffusion by small groups and individuals (see Roberts in press a). Those involved in the spreading and development of the new technology were frequently seen as having had special status. V. Gordon Childe famously articulated this in his highly influential concept of itinerant metal smiths (e.g. Childe 1930) that lay at the heart of his schemes of social complexity and class construction in later European prehistory (see Rowlands 1971; Wailes 1996).

The application of radiocarbon dating in the mid 20th century enabled the first independent chronology for early metal objects and metal production. Colin Renfrew used these to challenge the established ideas of *ex oriente lux* (e.g. Renfrew 1967, 1973) arguing instead for the independent discovery of metallurgy in southern Iberia on the basis that the radiocarbon dates were apparently so much earlier than for its neighbouring regions that the only explanation must be indigenous development. In other regions of Western Europe, the discussion of origins has concentrated upon neighbouring regions where there is earlier evidence of metal objects or metal production with diffusionist models for the earliest metal use remaining uncontested.

The mid 20th century also saw the earliest systematic archaeometallurgical investigations in Western Europe. These were motivated by the desire to provenance prehistoric copper, bronze, and latterly gold objects to a particular region, or more specifically an ore source. Programmes of compositional analysis were established such as the vast Stuttgart based *Studien zu den Anfängen der Metallurgie (S.A.M.)* project for copper, copper alloys and gold (Junghans et al. 1960, 1968, 1974; Hartmann 1970; 1979; 1982). Unfortunately, the inability to match many metal object compositions to ore sources reliably meant that the provenance projects were unable
to fulfil their original purpose (see Tylecote 1970). Nonetheless, researchers sought to use the data to address whether there were distinctive metal composition groupings in space and time (cf. Butler & Van der Waals 1964; Waterbolk & Butler 1965) and whether these could be equated with the defined cultural groupings such as the Bell Beaker culture which stretched throughout central and western Europe during the later third millennium BC (e.g. Case 1966; Harrison 1974). During the 1970s with the integration of archaeological fieldwork and archaeometallurgical analysis on projects that were specifically directed towards the investigation, recording and dating of features related to metal production in a locale or region. The purpose now was to reconstruct the production of copper objects in order to investigate the raw materials, technology and techniques that were used. The earliest and most influential of these projects was an ambitious survey of the mining and metallurgy evidence in the Huelva area of southwest Spain (Rothenberg & Blanco-Freijeiro 1980; 1981). The data that this and subsequent projects have generated inspired experimental replications that could be informed by and compared to archaeological and archaeometallurgical data (e.g. Happ et al. 1994; O’Brien 2004; Rovira & Guttierez 2005; Timberlake 2005; 2007). These address fundamental technological questions surrounding metal objects: what they were made of, how they were made, and where the ore came from (e.g. Tylecote 1987; Craddock 1995).

Whilst new methods of archaeological excavation, archaeometallurgical analysis and radiocarbon dating all demonstrably transformed the investigation and interpretation of early metal objects and metal production, the case for archaeological theory beyond culture-historical and technological/functional perspectives is far less convincing. As many prehistorians in Western Europe appear unable to dismiss entirely the validity
of ‘cultures’, refuse to re-define it or introduce an alternative, no new perspectives are introduced. Though social evolutionary models are occasionally promised, the outcome tends to consist of detailed descriptions of technological changes through time that are argued to signify increasing social complexity (cf. Childe 1944; e.g. Strahm 1994). More subtle perspectives have argued that metals were prestigious and tradable as well as being symbols of elite power and potentially subject to elite control, but they were not produced by full time specialists and did not play a crucial role in social change or the growth of social complexity in prehistoric societies (see Gilman 1996). The strong trend towards researching and modelling at local and regional dynamics of early metal (e.g. O’Brien 2004) has meant that broader perspectives have been largely descriptive rather than analytical. They compare the exploitation of different ore sources and the presence of specific production techniques and objects forms. It is argued that this approach provides few explanations regarding the presence or nature of metal and is unable to explore how prehistoric communities shaped this process.

To understand the transmission of metal objects and metal production practices through space and time requires going beyond looking at the physical and chemical conditions of production or the final properties of the object to examine and compare the available choices and subsequent decisions that influenced the creation, use and deposition of metal. The knowledge, skills and tools that would be required to perform each identifiable transformation need to be assessed to analyse how variation and change could have been enacted. In particular, it is important to ask whether existing circumstances and technologies could have led to independent discoveries of metallurgy, or if sufficient metallurgical inspirations could have derived from contact
with a metal object or knowledge of potential ores and the involvement of fire, or if the process required gaining expertise from experienced individuals. In order to explore the nature of early metal, a systemic approach that encompasses each aspect of early metal creation, use and deposition to reveal a biography (cf Gosden & Marshall 1999) that is general rather than specific is required (cf. Lechtman 1977; 1996; Hosler 1995; Ottaway 1994, 2001; Killick 2001; Fontijn 2002/3; Needham 2004; Ehrhardt 2005). This would entail the selection of an ore or ore source; the ore extraction, processing and distribution; the smelting, melting and alloying; the casting, manipulation and design of objects; the potential object uses; the circulation of the objects; the extent of object recycling/re-melting; and the nature of object deposition. Rather than being connected through linear sequences, this approach emphasises the dynamic nature of the many different inter-relationships existing between the different aspects (cf. Kingery 1993; 1996; 2001; Knappet 2005). The actions taken and not taken, the knowledge, skills and tools needed to perform the transformation and the consequences of decisions can be assessed. The purpose is to obtain insights into the broader spatial and temporal patterning in the choices and actions underpinning the changes and continuities in transmission reflected in early metal and analysing these in the context of the socio-economic and ideological dynamics that underlay these prehistoric societies.

**When is the earliest metal in Western Europe?**

To analyse the appearance of early metal in Western Europe, it is necessary to address metallurgical origins from the broader European perspective and assess the earliest evidence for gold, lead, silver, copper-arsenic, tin-bronze as well as copper (cf.
Kassianidou and Knapp 2005; Ottaway and Roberts 2008). It is during the mid 6th millennium BC that the earliest native copper and copper oxide exploitation is found in southeast Europe on sites such as Lepenski Vir (Srejovic 1972) and Divostin in Serbia (Glumac 1988) and Durankulak in Romania (Todorova 1999). The dating of copper ore extraction at Rudna Glava, Serbia to the late 6th millennium BC (Jovanovic 1991; Pernicka et al. 1993; Boric and Jovanovic in prep) and at Ai Bunar, Bulgaria, to the early 5th millennium (Chernykh 1978) together with many contemporary native copper or copper oxide beads, hooks, needles and awls at sites as far west as Neszmely, Hungary (Bognar-Kutzian 1976) and Coka, Serbia (Bailey 2000) confirms relatively extensive exploitation during this period (see Thornton 2002; Krause 2003; Zachos 2007 for reviews).

The earliest smelting of copper ores is less clear due to the ephemeral nature of the evidence, the relative lack of analyses to determine whether smelting took place, and the inability to distinguish smelted copper from native copper (see Wayman & Duke 1999). There is analysed copper smelting slag at Belovode, Serbia dating to the late 6th millennium BC (Radivojevic 2007) and in the early 5th millennium BC at Selevac, Serbia (Glumac & Todd 1991) and Promachon-Topolnica (Koukouli-Chrysanthaki & Bassiakos 2002) on the border of Bulgaria and Greece together with unanalysed material interpreted as smelting slag throughout southeast Europe at sites dating to the early 6th-5th millennium BC (see Glumac & Todd 1991; Thornton 2002; Zachos 2007 for a review). Further west, the excavation of a cemetery at Zengővákony in southwest Hungary revealed small pieces of smelting slag in a grave. Though excavated in the pre-radiocarbon era, the subsequent radiocarbon dating of the ceramic sequence places it in the late 5th millennium BC (Glumac & Todd 1991, 14).
The earliest exploitation and working of gold occurs in southeast Europe and subsequently spreads throughout eastern Europe during the mid 5th – 4th millennium BC, as demonstrated most spectacularly in the objects adorning the burials at Varna in eastern Bulgaria (Renfrew 1986; Makkay 1991). In contrast, the earliest gold objects found to the east and west only date to the 4th and early 3rd millennium BC (Gopher et al. 1990; Primas 1995). Similarly, the earliest appearance of silver objects occurs in a spectacular deposit from Alepotrypa cave in southern Greece also dated to the mid 5th – early 4th millennium BC (Muhly 2002), pre-dating the silver objects found in Bulgaria and Rumania from the 4th millennium BC. The earliest evidence for tin bronze is a single piece of slag from Hungary, reportedly dating to the late 5th millennium BC (Glumac & Todd 1991). However, as this find predates the earliest occurrences of copper-tin alloys in this region by over a millennium, it may well be an isolated case of accidental mixed smelting of copper ores with other tin-bearing ores.

In central Europe, the recent excavations at Brixlegg, Austria revealed a small hearth where copper fahlores that had been subjected to heat treatment, a small quantity of smelting slag and a copper strip and bead. The radiocarbon dates for the layer (SE 6) gave a broad range of 4500-3650 cal BC (Bartlehein et al. 2002; Höppner et al. 2005). However, the ceramic material recovered is typical of the metal importing Münchhofen culture dated c. 4500-4000 cal BC (Matuschik 1992; Nadler & Zeeb 1994), which makes a date of the later 5th millennium BC more probable. This makes Brixlegg contemporary with, rather than later than, the earliest evidence for sulphidic ore smelting further east as demonstrated by the recent slag analyses in east Bulgaria on samples dated to the late 5th to early 4th millennium BC (Ryndina et al. 1999). It is also far earlier than the subsequent smelting sites as at Götchenberg, Austria dating to
3580-3370 cal BC (Lippert 1992; see Krause 2003 for review). In contrast, the
evidence of copper objects in the Pfyn (c. 3800-3300 BC) and Cortaillod (c. 4000-
3300 BC) cultures of the western Alpine region also dates significantly later than
Brixlegg (Strahm 1994; 2005). Debates concerning the extent of primary as opposed
to secondary metal production during this period remain unresolved after recent
critical re-evaluations (see Fasnacht 1991; 1995; Rehren in press).

To the south of the Alpine region, there is tentative but growing evidence to suggest
that copper objects produced through smelting and dating to the 5th millennium BC
were present in northern Italy in addition to the three copper flat axes originally
proposed by Barfield (1966, 63). Though doubts have been expressed regarding these
due to the lack of contextual information (Skeates 1994, 9-12), the recently
discovered copper objects in 5th millennium BC (Mid-Late Neolithic) contexts at sites
in northeast Italy such as Bannia-Palazinne di Sopra and S. Andrea di Travo
(Giumlia-Mair 2005) and the dating of the awl found at the Arene Candide site in
northwest Italy to late 5th millennium/earliest 4th millennium BC (Skeates 1994;
Maggi & Pearce 2005) demonstrate more convincingly the presence of metal during
this period. The recent radiocarbon dating of mining tools found at Monte Loreto in
northwest Italy places copper ore extraction during the mid 4th millennium cal BC
(Maggi & Pearce 2005). Further west in Sardinia, copper and silver objects and
evidence for copper and silver smelting at sites such as Su Coddu are known from the
Ozieri and sub-Ozieri cultural phases which span the late 5th to the later 4th
millennium BC at sites such as Grotta sa Korona di Monte Majore and Cuccuru
Arrius (Lo Schiavo 1988; Lo Schiavo et al. 2005), whilst in Corsica at the site of
Terrina IV, copper objects and copper smelting has been radiocarbon dated to the later
4th millennium cal BC (Camps et al. 1988). However, barring two objects in northern Italy, no silver objects have been found beyond Sardinia in the central Mediterranean or Western Europe until the end of the 3rd millennium BC (Primas 1995).

In southeast France, the copper awls, dagger and awl fragments and lead beads were found in contexts at the site of Roquemengarde (Guilaine 1991) that have been radiocarbon dated to the later 4th millennium cal BC. However, the occasional discoveries of objects more typical of other regions with older metallurgical traditions to the east, such as northern Italian ‘Remedello’ style daggers, western Swiss style spiral pendants and even a gold repoussé diadem whose closest parallels are in the Balkans, raises the possibility of earlier dates (Elèure 1982, 56; Guilaine & Eluère 1997, 176; Ambert & Carozza 1998, 160-1). This pre-dates the earliest evidence for copper ore extraction at Vallarade, Cabrières from c. 3100 cal BC which is virtually contemporary with the earliest copper smelting at nearby La Capitelle du Broum (Ambert et al. 2002; 2005; Bouquet et al. 2006) and Pioch Farrus 448 (Espérou et al. 1994). The analysis of the slag, slagged ceramics and partially reduced ores have revealed the significant presence of both oxidic and sulphidic ores (Rovira & Ambert 2002a, 2002b; Bourgarit & Mille 2005; Bourgarit et al. 2003; Bourgarit 2007) with the probability that co-smelting occurred.

The picture in Iberia is more complicated. There is fragmentary evidence of copper oxide smelting slag at Cerro Virtud, southeast Spain which has been radiocarbon dated to the first half of the 5th millennium BC (Delibes & Montero-Ruiz 1997; Montero-Ruiz et al. 1999; Ruiz Taboada & Montero-Ruiz 1999). However, it is at least a millennium older than any other evidence of smelting or anything metallurgical.
in Iberia (e.g. Montero-Ruiz 1994; 2005). It comprises a piece of slag adhering to a single ceramic sherd that was excavated under rescue conditions from a site disturbed by mining and it is dated to a layer, rather than by associated organic material or feature, which the authors maintain was untouched in spite of the circumstances of excavation. Whilst sites such as El Palomar and Terrera Ventura in southern Spain have been cited as potential evidence for 4th millennium BC copper smelting (Montero-Ruiz 2005), the context of the evidence is not secure whilst the potentially late 4th millennium BC at the sites such as Rotura, Sala 1 and São Bras 1 remains unanalysed (Monge Soares et al. 1994). It seems probable that copper smelting occurred in southern Iberia during the late 4th millennium – early 3rd millennium BC and is confirmed throughout much of Iberia during the early- mid 3rd millennium BC at sites such as Bauma del Serrat del Ponte (see Goncalves 1989; Gómez-Ramos 1999; Delibes de Castro & Montero-Ruiz 1999; Fernandez Manzano & Martinez 2003), probably making it contemporary with the earliest gold (Perea 1991; Pingel 1992). Compositional analysis in south-central Portugal has even demonstrated the recognition and deliberate selection of arsenical copper during the later 3rd millennium BC, probably through the exploitation of arsenic rich ores (e.g. Müller et al. 2007). Since Chinflón, southwest Spain has been re-dated to the late 2nd millennium BC (Pellicer & Hurtado 1980; Rothenberg & Andrews 1996) no copper mine has been securely dated in Iberia until the early 3rd millennium BC (cf. Hunt-Ortiz 2003) as at El Aramo, northern Spain (Blas Cortina 2005).

To the north and west of the Alps in central Europe and to the north of the Pyrenees in Western Europe, there are no metallurgical sources in the geology until Wales, western and northern Britain and Ireland. In northwest continental Europe, it has been
argued that this contributes to the existence of a “Chalcolithic frontier” which experienced a delayed adoption of metal (e.g. Brodie 1997; 2001). Unsurprisingly, the evidence for metal production throughout this region is limited with the two copper droplets found in a hearth at Val-de-Reuil, Seine Valley, dating to the late 3rd millennium cal BC (Billard et al. 1991) represents a substantial discovery (see Meurkens 2004). However, the recent re-analysis of early metal objects reveals a far earlier initial presence than might be expected. The dating of the recently excavated collective burials at Vignely in north central France of which one, a child of around 5 years old, had a necklace of nine copper beads, produced a range of 3517-3357 cal BC (Mille & Bouquet 2004) making it older even than the earliest metal objects throughout southern France (Guilaine 1991; Roussot-Larroque 2005). Similarly, copper objects are known from the north Alpine region and the northern temperate regions such as the great European plains and even southern Scandinavia from the late 5th millennium BC (e.g. Ottaway 1973; Klassen 2000; Klassen et al. 2001). By comparison, the earliest gold objects beyond the Mediterranean are thought to date to the mid-late 3rd millennium BC (Hartmann 1970; 1982; Elèure 1982; Primas 1995).

There is a broad consensus placing the appearance of metal in the mid 3rd millennium BC in northwest continental Europe (Cauwe et al. 2001; Warmenbol 2004) though typologically earlier objects have been recovered as far west as Brittany (Briard & Roussot-Larroque 2002). Moving across the Channel, surveys and excavations of the copper ore sources in Wales have revealed extraction activities beginning in earnest c. 2100/2000 cal BC onwards (Timberlake 2002; 2003). The copper sulphide ore extraction and possibly smelting in southwest Ireland at Ross Island c. 2400 BC onwards (O’Brien 2004) therefore probably represents the earliest copper production
in northwest Europe. The only other broadly contemporary evidence for metal production consists of a splash of arsenical copper found in a midden at Northton on the Isle of Harris in Scotland (Brodie 1997) that is dated to the late 3rd millennium BC. Whilst there is typologically dated evidence for copper or gold objects in Ireland dating to the earliest period of metal production beyond the metal axe marks in the Corlea 6 wooden trackway in the Irish Midlands dendro-dated to 2259±9 BC (O’Sullivan 1996), there are several later 3rd millennium cal BC radiocarbon dates in southern Britain for copper and gold objects found in the Bell Beaker burial sites of Barrow Hills, Shrewton, Barnack, Chilbolton and Amesbury (see Needham 1996 for review; Fitzpatrick 2002).

The appearance and adoption of tin-bronze alloys throughout Western Europe and beyond appears to have been a sporadic process. Individual objects made of copper with low additions of tin appear in Montenegro, central Germany, northern Italy and northern Spain during the earlier 3rd millennium BC (Müller 2003 Krause 2003, 210; Fernandez Miranda et al. 1995; Primas 2002) but only reaching southern Iberia during the early 2nd millennium BC (Montero 1994). Whilst the ability to create tin bronze can be demonstrated at an early date and appears to be transmitted from east to west, the adoption and production of bronzes with consistently high percentages of tin only occurred significantly later throughout many regions of Europe (Pare 2000). In contrast to this is the very rapid transition from the use of pure copper or arsenical copper to tin bronze in Britain and Ireland during the late 3rd millennium BC (Needham 1996; O’Brien 2004).

How did Metallurgical Transmission occur?
The relatively abundant presence of colourful outcrops of copper ores throughout Iberia, southeast France, Wales and southern Ireland would seem to imply that the earliest prospecting in Western Europe would have presented few challenges (Figure 1a-d). However, the presence of other brightly-coloured mineral sources and the diversity of the copper ore colours could have been a source of confusion for inexperienced prospectors. Whilst it is highly likely that prehistoric communities would have observed copper ores during the pre-metallurgy period, they would also have observed many other mineral sources. As there is no evidence of copper ores or native copper being exploited during the pre-metallurgical period as occurs in southeast Europe, there is no sense that a distinction of copper-bearing minerals had been made or their having any identifiable significance until being recognised for their metallurgical properties. If consideration is given to the differing requirements for smelting oxidic and sulphidic copper ores, then not only copper ores have to be identified but also the copper ores that can be smelted employing existing practices. Due to the variation in regional geologies, environments and in the accessibility of copper ores, the discovery of new sources requires flexible prospecting techniques as well as expectations. The practice of prospecting would therefore have been partially a process of building on accumulated knowledge of the local landscape and partially on the experience that enabled the correct identification of an ore source and an ore type. It is also probable that, rather than envisaging a systematic landscape survey, the single discovery of a copper, gold, lead or tin source would lead to intensive prospection of the surrounding area for further potential sources.
When compared to later mining techniques (e.g. Craddock 1995), the evidence for surface and sub-surface extraction of oxidic and sulphidic copper ores\(^1\) in Western Europe at sites such as Les Neuf-Bouches, Cabrières, southeast France from c. 3100 BC (Bouquet et al. 2006), Ross Island, southwest Ireland from c. 2400 BC (O’Brien 2004) and Copa Hill, central Wales from c. 2100/2000 cal BC (Timberlake 2002; 2003) appears simple and straightforward\(^2\). The presence of earlier and more extensive underground mines, such as the variscite mines at Can Tintorer, northern Spain (Blasco et al. 1998; Bosch 2005) dating to the 5\(^{th}\) millennium BC or the flint mines at Cissbury or Grimes Graves in southern England dating to the 4\(^{th}\) millennium BC (Barber et al. 1999), implies that copper extraction represented an adaptation of earlier practices. However, this does not mean that anyone seeking to extract copper ore innately possessed the necessary expertise to do so. Ore veins were followed underground at copper mining sites such as El Aramo, northern Spain (Blas Cortina 2005), Pioch Farrus IV, Cabrières, southeast France (Ambert 1995) and Ross Island, southwest Ireland (O’Brien 2004) despite the greater need for labour as well as the organisation and expertise needed to facilitate the movement of miners and their equipment, in providing adequate ventilation, illumination and drainage, and bringing the ore to the surface, all whilst ensuring that the underground structures did not collapse. Opening new sources nearby would have required substantially less effort and expertise but there is little evidence to suggest that simply any ores or ore sources were exploited randomly. For each mining site the range of radiocarbon dates indicate a long-term commitment over centuries though the evidence of inhabitation in the

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\(^1\) Unfortunately, the evidence for gold, lead and tin extraction is non-existent (cf. Weisgerber & Pernicka 1995; Meredith 1998), probably because they derived from placer deposits in streams and surface collection, both of which will have left very ephemeral evidence.

\(^2\) Compositional and lead isotope analysis has traced metalwork assemblages to potential mines that remain currently undated as in Mocissos and Tharsis in southwest Iberia (Nocete 2004; Müller et al. 2007), Herrerías in southeast Spain (Delibes et al. 1989; Montero 1994, 223).
immediate environs is limited. For ore extraction to occur, there are the tools and equipment such as stone hammers and antler picks (e.g. Pascale 2003; Timberlake 2003) that would have to be made and carried, the food that would have to be acquired, the fuel that would have to be sourced for food but also larger quantities for fire-setting (cf. Weisgerber and Willies 2001) and people who would have to be organised, even if rich ore sources were nearby as in southern Iberia (Montero-Ruiz 1994; Hunt-Ortiz 2003). It would not have been possible to procure everything in the close vicinity of any mining sites, whether due to the stone resources, food production or the distance from inhabitation sites. The implication is that there would have to have been dedicated mining expeditions that had access to the ore. This would have required the active participation of a small group or community containing several individuals having relevant expertise. Their involvement would be needed in the processing or beneficiation of the ore whether close to the mining site as at Roque Fenestre and Farrus 448, southeast France (Ambert et al. 1984; Espérou et al. 1994) or within inhabitation areas further away at Cabezo Juré, southwest Spain (Nocete 2004) as well as in its subsequent movement. There are ongoing debates with certain scholars proposing the control of copper ore sources and production by specific groups (e.g. Nocete 2001, 2004) as well as those arguing that the abundance of copper ore and relatively widespread evidence of copper working means that this would not be possible (e.g. Suarez et al. 1986; Rovira 2002).

All the analysed smelting evidence can be characterised from a technological perspective as closely resembling each other - small scale, relatively low temperature processes carried out under poorly reducing conditions on oxidic and/or sulphidic ores in small stone and clay structures and/or ceramic crucibles with no intentional
addition of fluxes and little consequent slag (Craddock 1999; Bourgarit 2007). The smelting would yield only small quantities of copper that would then have to be refined in a separate process. There are several sites where refining rather than smelting has been identified, but there remain many that are assumed to have smelting evidence that require analysis. There is no evidence for any fundamental changes in the smelting practices during the 4th and 3rd millennia BC in Western Europe.

Whether a transfer of existing pyrotechnological capabilities during the pre-metallurgical period to the smelting of metal can be envisaged depends on the characteristics of the processes involved. The extensive presence of ceramics throughout Western Europe before metallurgy provides the most promising evidence though there are no known ceramic firing sites. It is highly probable that pottery, as elsewhere in Europe during this time, was fired in an open bonfire, which would render the process virtually invisible archaeologically (see Orton et al. 1997, 127-130). It is therefore the experimental reconstructions of ceramic open bonfire firings that provide the clearest indications of the pyrotechnological abilities (e.g. Gosselain 1992; Livingstone-Smith 2001; McDonnell 2001). Characteristics of this open firing technique are a lack of control, rapid changes in temperature, an oxidizing atmosphere and a duration varying from several minutes to several hours. Though temperatures of c. 1000°C can occasionally be reached, this is only for a very short duration and cannot be maintained before dropping back to 600-800°C or lower. This failure to sustain a sufficient temperature that is comparable to experimental reconstructions of...
The smelting of oxidic and/or sulphidic ores based on evidence and/or probable conditions in southern Iberia (Rovira and Gutierrez 2005), southeast France (Bourgarit et al. 2003), Wales (Timberlake 2005; 2007) and southwest Ireland (O’Brien 2004), the oxidizing rather than reducing atmosphere, and the lack of control over both makes it unlikely that copper smelting using a ceramic open firing method could have occurred.

Furthermore, it is unlikely that charcoal was used in the firing of ceramics or whether its recognition and use occurred before metallurgy. Wood, peat and dung would have been available and perfectly sufficient in the creation of pottery and other activities involving heat and fire and there does not appear to have been any pyrotechnological reason for charcoal to be employed. For metallurgy, the use of charcoal is particularly important, not simply due to its ability to create high temperatures using relatively small quantities in a small space, but due to it being a source of highly-reducing carbon monoxide gas (see Horne 1982; Craddock 2001). This makes it ideal for smelting copper ores and its absence renders the smelting process far less effective if not completely impossible. If any transfer of pyrotechnological knowledge did occur, it could not have been straightforward or simple. If independent experimentation led to the successful smelting of copper ores then there would have to have been significant alterations to the existing practices as well as the independent motivation to attempt such experimentation in the first place. Neither does it appear that copper smelting could have been consistently achieved with only a partial knowledge of the process involved – such as the ability to identify copper ores (as well as differentiate between oxidic and sulphidic ores), or the need for high temperatures. As modern experiments have shown, smelting needed to be carried out within a fairly narrow
margin of error or else the entire process would fail. Though lead could be smelted at lower temperatures, there is no evidence that it preceded the smelting of copper in Western Europe. Similarly, there is no evidence for gold objects preceding copper despite gold melting being a more straightforward process, albeit at a comparable temperature to copper smelting. It is argued that for smelting technology to spread, the expertise would have to be learnt in one place and applied elsewhere. This could therefore apparently only occur either through the movement of individuals or groups possessing the smelting skills.

Though there are few smelting sites that have been comprehensively and carefully excavated and analysed, where this has occurred there is evidence that smelting continued to be practiced for centuries in the same place whether at La Capitelle du Broum, southeast France (Ambert et al. 2002; 2005), Cabezo Juré, southwest Spain (Nocete 2004) or more tentatively at Ross Island, southwest Ireland (O’Brien 2004). The nature of these places varies - in the southern Iberian regions copper smelting has been found in the large walled settlements such as Los Millares (Arribas et al. 1989; Molina et al. 2004), smaller fortified sites such as Cabezo Juré (Nocete 2004; Nocete 2006) and unfortified sites such as Almizaraque (Delibes et al. 1986; 1989; Müller et al. 2004). This diversity is also seen in southeast France with the excavation of the extensive double-walled structures at the “metallurgical village” of La Capitelle du Broum (Ambert et al. 2002; 2005) in contrast with settlement sites such as Al Claus (Carozza et al. 1997; Carozza 1998) with less substantial structures. Though there is only a single known potential smelting site in Ross Island, southwest Ireland, its temporary huts stand in contrast to the sites in the other regions (O’Brien 2004). These places where copper smelting occurred, whether in the earliest form or
centuries later, appear to be located close to the extraction and ore processing sites, generally close to the available ore sources. The surviving evidence of the smelting equipment comprises thick-walled open-mouthed ceramic vessels as in Iberia and southeast France (Rovira & Ambert 2002a; 2002b) as well as clay lined hearths in southern Iberia as famously excavated at Los Millares (Hook et al. 1989; 1991) (Figure 2) and Zambujal (Müller et al. 2007). The virtual absence of such structures in Ireland and Britain can be explained by the potentially archaeologically ephemeral or even invisible evidence from smelting (cf. Timberlake 2005; 2007). The virtual absence of ceramic or stone tuyère fragments throughout Western Europe and beyond during the 4th and 3rd millennia BC (Roden 1988) has led to suggestions of wind potentially playing a greater role than previously acknowledged (e.g. Happ 2005; Nocete 2004; Nocete 2006; Bourgarit 2007, 7-8).

Arsenical copper is probably the earliest intentional copper alloy appearing throughout Western Europe from at least the 3rd millennium BC. Its origins are hard to assess as some of these are intentionally-produced alloys and others were probably the result of accidental smelting of copper ores with arsenic impurities or mixed ore charges. There does not appear to be any systematic shift from producing copper metal to copper arsenic alloys. Rather, in certain instances, there appears to be the opportunistic exploitation of copper arsenic metals due to the smelting of copper ores rich in arsenic that may have been accompanied by an awareness of how the metal could be reproduced. This translates into the creation of specific object forms such as elongated awls and sheet metal at Zambujal south-central Portugal (e.g. Müller et al. 2007) and possibly halberds and daggers in Ireland (Northover 1989) as well as the contemporary presence but less clearly deliberate exploitation of the alloy as in
southern Iberia (Montero-Ruiz 1994, 247-263; Hunt-Ortiz 2003 contra Hook et al. 1991; Keesman et al. 1991/2). There is no evidence that gold, copper or lead were mixed to form alloys. These widely differing rates of adoption of tin bronze do not appear to be related to the distance away from the relatively scarce tin ores throughout Europe (Pernicka 1998). Rather, it appears to relate to regional preferences (see Primas 2002; Guimlia-Mair & Lo Schiavo 2003) even though the smelting of tin ore or the direct creation of copper-tin through mixed ore smelting would have been within the capabilities of a copper smelter.

The realisation that the metal can be cold-worked for a longer time if heated in between shaping will not have escaped the notice of people who were used to fire-harden wood, heating flint and firing pottery and it is therefore no surprise to find it present throughout Western Europe in the earliest objects. However, the application of heat to create a liquid from a solid that could then be poured into a mould to form a new object when cooled, does not have real parallels in pre-metallurgical societies but are still present in the vast majority of the earliest copper objects in Western Europe (e.g. Rovira & Gómez-Ramos 2004). The excavation of equipment relating to the creation of copper and gold objects, such as moulds, hammers, tongs and anvils, is very sparse relative to the number of objects that have been recovered. This is partially due to the difficulty in identifying the specific tools that would have been employed, but more probably related to the rapid degradation of sand moulds (e.g. Ottaway & Seibel 1997; Eccleston & Ottaway 2002), the fragmentation of clay moulds (e.g. Ottaway 2003) and the decomposition of any wooden objects such as patterns, models and containers.
Where exhaustive typological research has been conducted on an object type such as beads and copper flat axes in southeast France (Chardenoux & Courtois 1979; Barge 1982) and flat axes, halberds and daggers in Ireland (Harbison 1969a; 1969b), it has revealed extensive morphological micro-variations based on several distinctive designs. Despite the possibility of specific object designs being reproduced in copper and gold, there is little evidence for any imitation beyond objects designed to worn as personal adornment (e.g. Barge 1982). It appears that the replication of specific objects occurred far less frequently than the creation of subtly new ones. The implication for the production of copper objects is that slight alterations on accepted norms occurred. Rather than re-use stone moulds or wooden patterns for shaping clay and sand moulds, new moulds would have to be made or the metal would have to be manipulated in a different way.

The quantity of metal objects produced is always going to be far greater than the number recovered. It is through the deposition or discarding of copper and gold objects in each region, rather than their recycling or re-melting, that the perception of the presence of metal is those prehistoric communities is shaped. Consequently, there is an unavoidable bias in the perception of metal use in the past towards regions or objects where higher metal deposition, (rather than recycling), occurred (cf. Needham 1998; 2001; Taylor 1999). However, there is little indication of large scale production even in regions surrounding mining and smelting sites. For instance, in southeast France there are only 1403 known copper objects dating to the later 4th millennium – mid 3rd millennium which is still double that of southeast Spain during the same period (Montero 1994) (Figure 3). The object forms involved range in diversity and emphasis with copper flat axes, beads, needles, fishhooks, awls, knives, daggers,
saws, sickles, spatulas, chisels found in Iberia (Delibes de Castro & Montero-Ruiz 1999). In contrast, there is a more restricted range with a distinct emphasis on copper beads in southeast France (Gutherz & Jallot 2005) and a virtual absence of any copper objects beyond flat axes, daggers and halberds in Ireland (Harbison 1969a; 1969b).

The life of metal objects after they are produced and before they are discarded or deposited is the most elusive part of their existence. Aspects such as where an object was taken, how it was used, how it changed possession, the perceptions that surrounded it and whether it was recycled, re-melted or re-cast may well be more important to understanding its presence than production or depositional practices. However, approaching any of these aspects is difficult using current archaeological and archaeometallurgical techniques. With a chronological resolution of centuries, it is the identification of broader patterns of metal movement, use and circulation relative to metal production sites that can be investigated. The extensive programmes of compositional and latterly lead isotope analyses of early copper objects in Western Europe reveals the circulation of metal objects from production centres. For instance, the vast majority of copper objects in Ireland and Western Britain conform to high arsenic and antimony, as well as a lead isotope, signatures that in all probability derives from Ross Island, southwest Ireland (Coghlan & Case 1957; Case 1966; Rohl & Needham 1998; Northover et al. 2001). This exploitation of a single source for several centuries by communities in a region can also be seen in southeast France when the high silver and antimony compositions and lead isotope levels were examined against the ores at Cabrières (Ambert 1999; Prange et al. 2003; Prange & Ambert 2005). In contrast, the recent re-analyses of compositional data in eastern Britain and continental northwest Europe reveals very different yet coherent
patterning, originally termed Bell Beaker metal (Butler & Van der Waals 1964; Butler & Waterbolk 1965), that appears to be formed from the mixing of metals from two obviously distant geological sources, with one perhaps even as far as northern Spain (Needham 2002). To investigate the archaeological contexts in which metal objects are found requires a high standard of excavation, recording and publication. As the vast majority of the metal objects in each region were accidentally discovered during the 19th to mid 20th century, the quality of the data tends to be highly variable. At best, it is possible to discern broad patterns that can be contrasted such as the concentrations of metal ornaments in burial contexts accompanying bodies as compared to the concentrations of flat axes placed elsewhere (e.g. Needham 1988; Guthertz & Jallot 2005).

Metals, Metallurgy and Material Traditions

It can be demonstrated that expertise would have to have been gained for certain aspects of metal production in Western Europe, such as the selection and smelting of the ore, for a successful transfer from individual to individual making it probable that metallurgical skills were restricted, whether intentionally or not. The inevitable or deliberate restriction of such crucial knowledge such as the correct raw materials, the smelting equipment or the sequence and timing of actions and addition of substances could have ensured that it remained in the hands of a few select groups of metal producers, who only passed on their craft to people of their choosing. If the ethnographic record is any guide, in virtually all instances this means specific members of an extended family or tribe with songs, rituals and taboos reinforcing the restricted knowledge and expertise. It is argued here that the requirement of a
metallurgical apprenticeship (cf. Keller 2001) and the subsequent movement of metallurgists, either returning to their original regions or settling in new ones, would create extensive yet fragile networks of expertise.

However, it is important not to over-emphasise the primacy of metal production techniques in this process. It is argued that the desires of the communities supporting metal production as metal consumers were actually more important. For metal orientated networks of production expertise to exist, individuals and communities are needed to invest in the acquisition of metal objects and metallurgical technology. It is even perhaps erroneous to discuss individuals in certain aspects of the metallurgy given the collective nature of so many of the production processes, including the ore prospection, extraction, processing and transport. Even the existence of part-time copper smelters or smiths, who are more likely to have had distinctive individual roles owing to their specialist expertise, required the commitment of the broader community to aid in the procurement of food and shelter as well as production and acquisition of the objects. There is no inherent functional reason why metal objects or metal production should be adopted by local communities or introduced by non-local communities. It is important to re-emphasize that the earliest copper, gold and lead objects were not necessarily superior to wood, bone, flint and ceramics for performing everyday tasks and that there were many obstacles and complications involved in metal production practices relative to those in existing materials. The distinctive colours, lustre, malleability and ability to carry decorations and be recycled can be proposed as attractive qualities for adopting metal (cf. Keates 2002). However, early metal objects and production practices were adopted due to specific community desires and standards (see Helms 1993; Sofaer Derevenski & Sørensen 2002; in press)
which created and reproduced spatially and temporally distinct metallurgical traditions throughout Western Europe (Roberts in press b).

Metallurgical traditions did not exist independently and were closely bound into other larger and more pervasive socio-cultural networks and traditions whose spatial and temporal variations are expressed through metal as well as other material culture (e.g. Sofaer 2006). For instance, the influence of the Bell Beaker phenomenon during the mid third millennium BC in creating and shaping existing copper metallurgical traditions varies throughout Western Europe (see Brodie 1997; 2001; Vander Linden 2006; 2007). In southeast France, there is a marked reduction in the diversity and quantity of metal objects (Ambert 2001), in Iberia new forms are simply added to the existing repertoire without any discernable change in the underlying technology (Rovira 1998; Rovira and Gomez-Ramos 2004), in northwest continental Europe and southern England communities are seemingly obtaining metal objects from two distant sources which are then melted, mixed together and re-cast (Needham 2002). In Ireland, despite the chronological parallels in the appearance of metal and Bell Beaker pottery and the discovery of several sherds at the metal production site of Ross Island, southwest Ireland (O’Brien 2004), metal appears to re-define existing traditions rather than adorn the dead in new burial rites as in southern England (Needham 1996; Fitzpatrick 2002). The extraction of the raw material for producing copper axes at a specific place, the widespread distribution of the flat axes, and the virtual absence of these axes in burial contexts parallels earlier traditions of polished stone axes in Ireland (e.g. Cooney and Mandal 1998). It is possible to observe the replacement of polished stone axes by metal flat axes throughout Ireland, demonstrated by the subsequent decrease of polished stone axes during the mid-late third millennium BC,
a process that is especially acute in southwest Ireland (O’Brien 2004, 562). It is
evidence that despite the many possibilities afforded by the new material and new
inter-connections generated by the technology, there were evidently boundaries in
form and composition that could not be transgressed. The ability to recycle metal
means that object forms created elsewhere could be melted down and converted into
more familiar shapes, even in regions far from copper ore deposits. It is this potential
fluidity of a widely recognised material that would have been important in the
sustaining and intensifying metallurgical networks and traditions (cf. Shennan 1993;
1999; Sherratt 1974; 1993). Despite the potential and possibilities, metal in the fourth
and third millennia BC is relatively small scale and its development is very gradual.
Neither the production nor the consumption of metal possesses serious enough
credentials to be considered a major, let alone revolutionary, influence in the broader
worlds of the communities involved (Chapman 2003; Bartleheim 2007).

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Figures

Figure 1a  Major Copper sources in Europe
Figure 1b  Major gold sources in Europe
Figure 1c  Lead ores and argentiferous lead ores in Europe
Figure 1d Major Tin ore sources in Europe

Figure 2 Clay ringed hearth structure at Los Millares, southeast Spain (Craddock 1995, 133)
Figure 3  Typical early copper objects found in southern Iberia featuring daggers (48-52), a flat axe (53), a chisel (55) and an awl (54) (Martin Socas et al. 1998, 923)