Development of metallurgy in Eurasia

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The authors reconsider the origins of metallurgy in the Old World and offer us a new model in which metallurgy began in c. *eleventh/ninth millennium BC in Southwest Asia due to a desire to adorn the human body in life and death using colourful ores and naturally-occurring metals. In the early sixth millennium BC the techniques of smelting were developed to produce lead, copper, copper alloys and eventually silver. The authors come down firmly on the side of single invention, seeing the subsequent cultural transmission of the technology as led by groups of metalworkers following in the wake of exotic objects in metal.*

Keywords: Eurasia, copper, gold, silver, transmission, mobility, craftspeople

Introduction

Modern debates regarding the spread of metal use in Eurasia can be traced to the work of Theodore Wertime (1964, 1973), who argued that the expertise required to smelt metal was such that it could only have been discovered once, and to Colin Renfrew (1969), who proposed multiple independent centres of metallurgical invention. Whilst subsequent surveys highlighted the potentially deterministic role of regional geologies (Charles 1980), and the increased quantity of new data (Muhly 1988), they did not resolve the issue. In the 20 years since, there has been a flood of new data from fieldwork and laboratory projects, as well as far greater access to regions throughout Eurasia. These have been accompanied by new theoretical paradigms in archaeology that have challenged the purely technological perspectives of the debate and demonstrated how early metallurgy was shaped instead by cultural forces of the societies involved. The foundations of this new approach can be traced to the eminent materials scientist Cyril Stanley Smith (1981) who argued that the adoption of metallurgy derived not from some technical or economic necessity, but from aesthetics and specific socio-cultural desires. People did not *need* copper tools; they *wanted* copper tools. After all, the earliest metal objects were not necessarily superior to wood, bone, flint, obsidian or ceramics for performing everyday tasks, and these other materials continued to be used for thousands of years alongside metal tools.

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Our aim is therefore not only to re-evaluate where and how early metallurgy occurred, but also to understand the broader processes underlying its transmission and earliest development. Within this there are several fundamental questions that we seek to address. Was metallurgy invented at a single place or invented independently in multiple locations throughout Eurasia? Is there significant variation when different metals are investigated and compared? What were the motivations for the invention and innovation of metallurgy and how did these occur throughout Eurasia?

We will show that metallurgy derived from the desire by the early agricultural and agro-pastoral communities in Southwest Asia (*c*. eleventh–ninth millennium BC) to adorn the human body in life and death using colourful ores and naturally-occurring metals. It is only in the subsequent millennia that the application of heat in a controlled reducing atmosphere led to the smelting of metallic ores to produce lead, copper, copper alloys, and eventually silver. The use of metals spread throughout Eurasia usually by the acquisition of metal objects as 'exotica' and often then by the movement of people possessing metallurgical expertise. However, the metals, production techniques and object forms used in each early region reflect local standards, implying a process of incorporation and innovation by the communities involved rather than a straightforward or inevitable adoption.

Metals, origins and chronologies

The development of metallurgy in Southwest Asia began long before the application of fire to naturally occurring metals. Indeed, the use of blue and green copper ores for beads, pendants and pigments was a critical step in the Neolithic, occurring at early agricultural and agro-pastoralist sites dating to the eleventh–ninth millennium BC (Figure 1a) at sites such as Shanidar Cave and Zawi Chemi in north-eastern Iraq, Hallan Çemi in eastern Turkey and Rosh Horesha in Israel (Yener 2000; Bar-Yosef Mayer & Porat 2008). The increased working of naturally-occurring or 'native' copper as well as copper and lead ores is demonstrated at sites such as Cayönü Tepesi in eastern Turkey, where metallographic analyses have shown evidence of annealing *c*. 8000 BC, indicating the early application of heat to the production process (Maddin *et al.* 1999). Native copper exploitation flourished in this core area through the seventh millennium BC while other metals, notably lead and (in the early sixth millennium BC) meteoritic iron, appear for the first time (Schoop 1999). Although the copper was probably still native, lead objects, such as the bracelet from Yarim Tepe in northern Iraq, if not actually made of lead (they have never been analysed), were probably smelted (Müller-Karpe 1990).

By the late eighth millennium BC, copper metal appears outside the core area of eastern Turkey and northern Iraq, such as the native copper beads from Tell Ramad in south-western Syria (Golden 2009) and from Ali Kosh in south-western Iran (Pigott 1999; Hole 2000), spreading as far as Mehrgarh in central Pakistan by 6000 BC (Kenoyer & Miller 1999; Moulherat *et al.* 2002). In at least two of these sites, initial copper use is concurrent with the appearance of obsidian imported from eastern Anatolia (Wertime 1973; Cauvin *et al.* 1998). Whilst seventh-millennium BC crucibles for either melting or smelting copper metal have been found at sites such as Çatalhöyük in central Turkey (Craddock 2001), these early technical ceramics remain both unique and controversial. The best documented

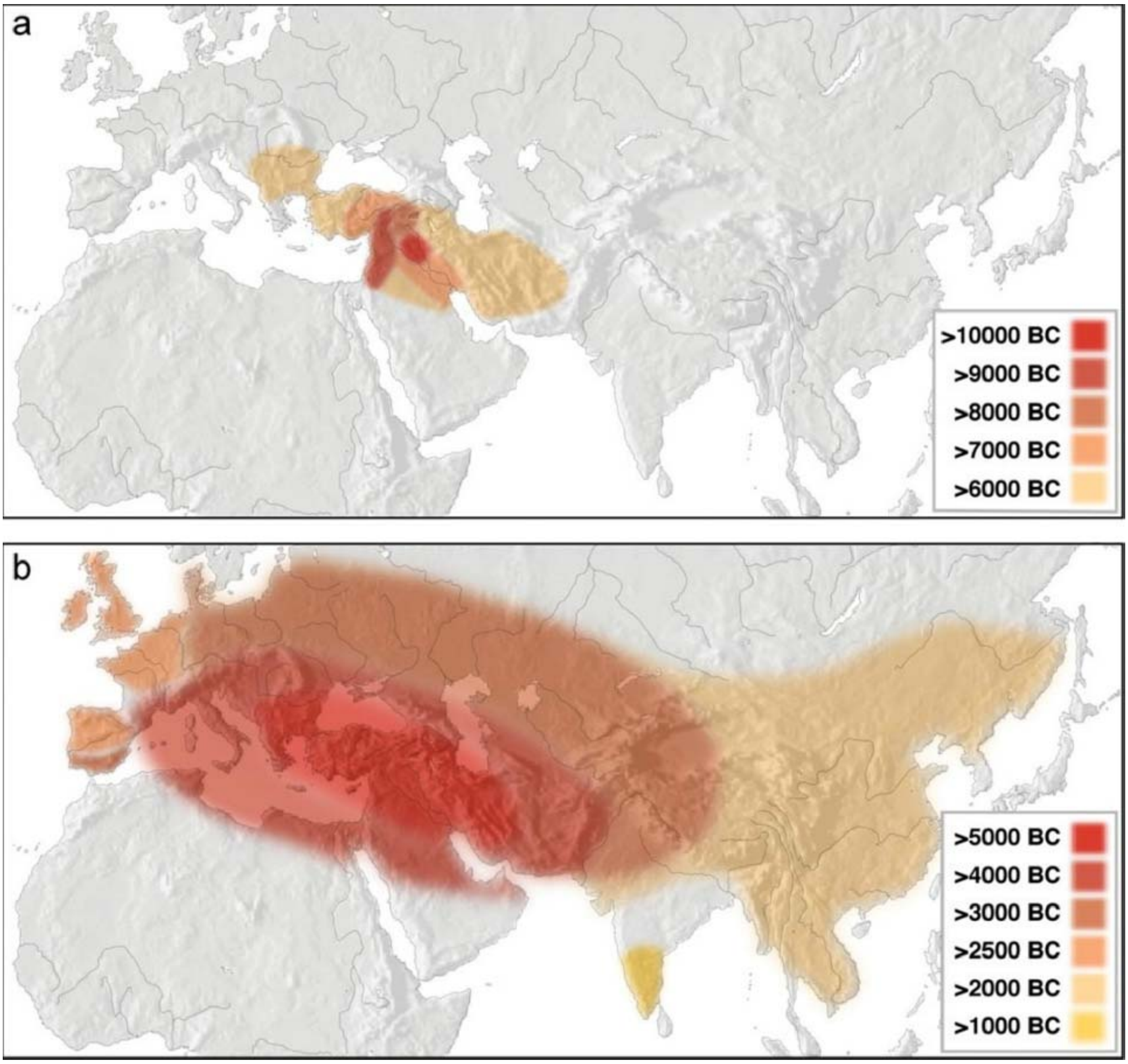

Figure 1. a) The exploitation of copper ores and naturally occurring copper metal; b) the spread of copper smelting technology.

early copper smelting sites occur in the late sixth/early fifth millennium BC in areas far removed from the Fertile Crescent, such as Tal-i Iblis in south-eastern Iran (Frame & Lechtman forthcoming) and Belovode in eastern Serbia (Radivojević 2007; Borić 2009). By the late fifth millennium BC, copper production became more common in eastern Turkey (Yener 2000) and began in the southern Levant (Golden 2009) and in Central Europe as at Brixlegg in Austria (Höppner *et al.* 2005). Given the virtually synchronous appearance of copper smelting throughout Southwest Asia and Southeast Europe, a single central region of invention is far more probable than many parallel independent discoveries (Figure 1b). This core region was probably in Anatolia, where copper ore and naturally-occurring copper had already been exploited for several millennia. However, future scientific studies comparing the technological practices of the various regions will be necessary before this debate can finally be settled.

In contrast, the earliest exploitation and working of gold occurs in the Balkans during the mid-fifth millennium BC, several centuries after the earliest known copper smelting. This is demonstrated most spectacularly in the various objects adorning the burials at Varna, Bulgaria (Renfrew 1986; Higham *et al.* 2007). In contrast, the earliest gold objects found in Southwest Asia date only to the beginning of the fourth millennium BC as at Nahal Qanah in Israel (Golden 2009), suggesting that gold exploitation may have been a Southeast European invention, albeit a short-lived one. Silver occurs rarely in native form, although examples of its early use are known, such as two mid-sixth-millennium BC beads from Domuztepe, south-east Turkey (Carter *et al.* 2003). By the early fourth millennium BC, metalworkers throughout Southwest Asia had discovered that certain argentiferous lead ores when smelted produced lead metal rich in silver, and that by oxidising the lead within specialised ceramic vessels, the lead oxide penetrated into the ceramic leaving the silver metal behind (Hess *et al.* 1998). This method, known as cupellation, was being practiced as far east as Central Asia by the mid-fourth millennium BC and possibly even earlier in Southeast Europe as suggested by the hoard of silver objects from Alepotrypa Cave in southern Greece dated to the mid-fifth/early fourth millennium BC (Muhly 2002).

By the late fifth/early fourth millennium BC, copper ores with natural impurities of arsenic and lead were exploited (whether knowingly or not) throughout Southwest and Central Asia and Southeast Europe to produce low-level copper alloys with useful qualities such as increased hardness or suitability for casting. By the mid-fourth millennium BC, copper alloys such as arsenical and antimonial copper were being intentionally produced. They were frequently selected for use over pure copper in certain prestige objects throughout much of this region as is most dramatically demonstrated in the famous Nahal Mishmar hoard from Israel (Golden 2009). Tin-bronze appears first in Southwest Asia by the end of the fourth millennium BC and is found in Central Europe and in Central Asia by the early third millennium BC (Primas 2002; Thornton 2007). As with almost all other innovations in early metallurgy, the adoption of tin-bronze was not immediate, but happened over centuries as cultural values changed and people learned to incorporate the new material into their socio-economic and socio-cultural systems.

The beginnings of metallurgy in Western Europe and in East and Southeast Asia have generated the most heated debates concerning independent invention *versus* diffusion. Many scholars now accept that the earliest dates for copper metallurgy in Europe indicate a punctuated east–west transmission primarily along major rivers and coastlines, starting in the late sixth millennium BC in Southeast Europe and culminating in the mid-third millennium BC in Britain and Ireland (Ottaway & Roberts 2008). The evidence for independently-invented metallurgy in southern Iberia (e.g. Ruíz-Taboada & Montero-Ruíz 1999) is fragmentary and the dating unreliable (see Roberts 2008). Rather than exploiting native copper or copper ores as in Southwest Asia, the earliest copper objects in Central, Northern and Western Europe were smelted from oxidic and sulphidic ores and appear concurrently with other forms of metal exploitation, including silver cupellation in Sardinia by the early fourth millennium BC (Lo Schiavo *et al.* 2005), lead in south-east France by the mid-fourth millennium BC (Guilaine 1991) and gold in southern Britain and Ireland by the mid-third millennium BC (Needham 1996). There is little uniformity in the mechanism and speed of the adoption process, with regional innovations creating a mosaic of metal use and metallurgical practices.

The initial arguments for indigenous metallurgy in East and Southeast Asia hinged primarily on the absence of evidence for significant contact between the central plain of China and the metal-using communities of Southwest and Central Asia. However, recent research on the western and northern borders of China has demonstrated the presence of mostly copper objects from the late fourth/early third millennium BC with links to communities on the eastern flank of the Eurasian Steppe, where copper, silver, and gold were in use by the late fourth millennium BC (Chernykh 1992; Mei 2000; Linduff & Mei in press). By the beginning of the third millennium BC, copper, arsenical copper and tin-bronze were being smelted from local ore sources in north-west China. Thus, the dating of copper and tin-bronze metallurgy in central China to the early to mid-second millennium BC implies a relatively rapid adoption rather than an indigenous invention (Linduff *et al.* 2000). The sudden emergence of full-blown tin-bronze metal production in neighbouring Southeast Asia from the early to mid-second millennium BC, as demonstrated at sites in Thailand and Vietnam, is a consequence of this same movement of ideas and possibly metalworking communities from the Steppe and/or Steppe-Forest zones (White 1997; Higham 2006; Pigott & Ciarla 2007; Higham & Higham 2009; White & Hamilton in press). The current debate therefore concerns how Eurasian metals and metallurgical technology were transmitted so rapidly across China's vast expanse to northern Southeast Asia and by what route (Pryce 2009).

Raw materials, technology and techniques

The integration of archaeological fieldwork and archaeometallurgical analysis over the past few decades has provided data on the mechanics of early metal production. The role of the archaeometallurgist is to characterise early metal production and metalworking techniques empirically, and then to compare these results with other sites to explore the local innovations that occurred with the spread of this technology. Furthermore, these changes must be placed back into their wider social context and related to contemporaneous transitions in other technological and cultural practices. While studies of metal artefacts continue to dominate the archaeometallurgical literature, there is a growing awareness that simple metalworking techniques were highly localised and passed between individuals, thus making studies of technological transmission using metallographic and chemical analyses of metal artefacts extremely difficult. In contrast, highly specialised knowledge is required for successful smelting of ores to metal, for the production of technical ceramics (e.g. crucibles, moulds, and furnaces), for the control of temperature and reaction times, and for the post-smelting processes required to remove impurities from the metal to make it a usable and desirable product. To understand these more involved stages in the metalworking process, greater attention has been paid over the past few decades to the importance of technical ceramics and the production of slag for the successful smelting of ores (e.g. Bayley & Rehren 2007; Hauptmann 2007).

Certain universal features categorise the early metal production of Eurasia, including the use of specialised ceramic fabrics for crucibles, moulds, and furnaces; the ability to source and prepare the correct raw materials; the importance of a good supply of fuel such as charcoal; some way to conduct and control air flow such as blowpipes or openings pointed towards prevailing winds; and the surprisingly low reducing conditions and temperatures needed to transform ore into metal (Bourgarit 2007). The earliest production of copper is often argued to have been carried out in small crucibles using very pure oxidic ores such as malachite and azurite that were directly reduced through the addition of charcoal, which would have provided a source of carbon monoxide. However, achieving the conditions necessary to completely reduce pure oxidic ores requires air-tight ceramic containers that can also withstand the high temperatures needed to melt the resulting product (1086°C for pure copper). Such highly-specialised ceramics had not yet been discovered at the beginnings of metallurgy in most regions, and there is certainly no evidence in early periods for the construction of elaborately sealed smelting structures.

Instead, many early copper smelting sites show evidence for the use of oxidic and sulphidic ores (such as chalcocite or bornite), whether mixed intentionally by the metalworker or naturally mixed by geological processes, smelted under mildly oxidising conditions. Even in such an oxidising environment, the combination of oxidic and sulphidic ores will lead to the production of copper via the so-called 'co-smelting' process, whereby the sulphur removes the oxygen from the ore at sufficiently high temperatures (Rostoker *et al.* 1989). In fact, relatively oxidising conditions are beneficial to mixed ore charges as they served to partially roast the sulphides, leading to higher yields of copper instead of unusable 'matte' (i.e. molten copper-sulphide). Thus, the idea of early smelting being based around 'pure' copper oxides in a fully reducing environment may need to be revised (Bourgarit 2007). In contrast to copper smelting, the smelting of argentiferous lead ores to produce silver would have required reducing conditions to produce the lead and subsequently oxidising conditions to separate the lead from the silver. Therefore, this would have necessitated understanding a distinctly different approach towards metal production (Hess *et al.* 1998). The melting of naturally occurring gold nuggets in a crucible would have been fairly straightforward in requiring only a comparable temperature to copper smelting of 1064°C (Raub 1995). By far the easiest metal to produce would have been lead which could be smelted from its ores at low temperatures in relatively weak reducing conditions (Müller-Karpe 1990).

The initial creation of a copper-arsenic or copper-antimony alloy was, most probably, a consequence of smelting arsenic or antimony rich copper ores. However, the subsequent widespread appearance of these alloys suggests that deliberate choices were being made in the production process, whether in the selection of ores or the mixing of metals. The majority of tin ore sources throughout Eurasia are concentrated in a narrow geological belt stretching from Europe to Southeast Asia, making them not only relatively scarce, but perhaps also facilitating the adoption of bronze throughout the Eurasian landmass via the steppes of Central Asia (Pigott & Ciarla 2007). Recent research has also demonstrated that tin-bronze may have been made from rare copper and tin bearing ores such as stannite (Cu_2FeSnS_4) or its oxidic weathering products, which are found in at least one location in western Iran (Nezafati *et al.* 2006), within the tin belt in Central Asia (Boroffka *et al.* 2002; Parzinger 2002), as well as in Iberia (Rovira & Montero-Ruíz 2002). Whether these ores led to the earliest manifestation of tin-bronze production in those regions has yet to be resolved. The presence of arsenic, antinomy and tin can in copper alloys, in comparison to pure copper, slightly lower the melting point, improve the quality of the cast, increase the hardness of the metal through cold-working, improve the ability to be hot-worked repeatedly and alter the colour (Northover 1989; Lechtman 1996). Nevertheless, the role of tin-bronze in early metallurgy appears to have been limited until its widespread appearance throughout Eurasia in the early to mid-second millennium BC.

Metallurgical transmission

The metal production process would not have been entirely novel, given that metal was preceded or paralleled by pyrotechnological activities creating other materials (e.g. ceramics) throughout Eurasia. However, there are sufficient differences in the necessary thermal and atmospheric conditions required to suggest that being proficient in metal production would require verbal instruction and visual demonstration under experienced individuals or groups for a successful transfer of knowledge. As smelting experiments have shown, even 'simple' smelting technology needed to be carried out within a fairly narrow margin of error or else the entire process would fail. The *châine opératoire* encompassing the selection of the correct raw materials, the sequences and timings of actions, the creation and identification of the right conditions, and the addition of substances would have to be memorised and practiced. The inevitable or deliberate restriction of metal production expertise could have ensured that at least certain aspects remained in the hands of select groups of metal producers, or were only incompletely transmitted to other groups. The transmission of this metallurgical expertise did not simply involve the intrepid wanderings and migrations of independent metalsmiths as influentially envisaged by the great prehistorian V. Gordon Childe (Childe 1930), but it did involve the movement of metalworkers, perhaps in broader social groups, who were able to access the necessary resources.

The societies who sought to possess metal objects or metal production techniques were highly influential in the adoption process (i.e. not merely passive recipients of the 'inevitable' new technology) and it is important not to over-emphasise the primacy of the production process. Even the existence of a part-time metalsmith required the commitment of the broader community to aid in the metalworking process. This includes supporting him or her in the collective parts of the production process such as ore extraction and processing and fuel collection and preparation, providing sustenance for specialised craftspeople, and aiding in the trade and consumption of metal objects. The consequence is a process, not only of metal adoption, but also metal innovation, as metal objects and production techniques were shaped to reflect specific community standards and desires. For example, the majority of the earliest metal objects in south-east France from the late fourth millennium BC are beads and pendants, suggesting a desire for ostentatious bodily adornment in the burial rite. This cultural proclivity is seen also in a diverse range of similar objects made from animal bones, horns, teeth, shells and stones. The subsequent introduction in the mid-third millennium BC of the distinguished and highly standardised metal repertoire of the Bell Beaker burial rite demonstrates a marked reduction in the diversity and quantity of metal objects (Ambert 2001). Hence, rather than showing how the presence of metal led to increasing technological innovation or intensification of production, the opposite appears to be the case. Similarly, the production of copper-arsenic alloys in south-east Iran occurs in the mid–late fifth millennium BC but is not more widely adopted until the mid-fourth millennium BC (Thornton in press). In the meantime, native copper working at small non-metal producing sites such as Tepe Yahya continued unchanged. The eventual shift to arsenical copper paralleled a larger societal preference for imported goods, such as turquoise or arsenical copper, over locally-available goods, such as steatite/chlorite or native copper. The adoption of a 'better' technology had little to do with material properties or metalsmith's choices, and everything to do with changing cultural mores and consumer demands.

Conclusion

Metallurgy in Eurasia originated in Southwest Asia due to the widespread adoption of, and experimentation in, pyrotechnology and the desire for new materials to serve as aesthetic visual displays of identity, whether of a social, cultural or ideological nature. This can be demonstrated through the early use of metal for jewellery and the use of ore-based pigments along with the continued use of stone, bone, and other materials for most tools. The subsequent appearance of metals throughout Eurasia is due to the acquisition of metal objects by individuals and communities re-inventing traditions of adornment, even in regions hundreds of kilometres from the nearest sources of native metals or ores. The movement of communities possessing metallurgical expertise to new ore sources and into supportive societies led to the gradual transmission of metallurgy across the Eurasian landmass. By the second millennium BC, metallurgy had spread across Eurasia, becoming firmly rooted in virtually all inhabitable areas (Sherratt 2006). The ability to smelt different ores, create different metals or increase metal production did not occur in a linear evolutionary fashion throughout Eurasia, but rather appeared sporadically over a vast area – a result of regional innovations and societal desires and demands.

There is no evidence to suggest that metallurgy was independently invented in any part of Eurasia beyond Southwest Asia. The process of metallurgical transmission and innovation created a mosaic of (frequently diverse) metallurgical traditions distinguished by form, composition and production techniques. It is within this context that innovations such as the earliest working of gold in the Balkans or the sudden emergence of distinctive tin-bronze working in Southeast Asia should be seen.

That said, the beginnings of metallurgy in the Americas appear to be entirely independent from Eurasia in their origins and development from the early cold-working of native copper from *c*. 5000 BC in the Eastern Woodlands of North America (Ehrhardt in press) and the early use of gold from 2000 BC in the central Andes of South America (Aldenderfer *et al.* 2008). However, the subsequent metallurgical trajectories in these regions provide little doubt that metal objects and metallurgical technologies in the New World were shaped by the same sorts of social and cultural mores that shaped early metallurgy in the Old World (Lechtman 1999).

The transmission of ideas, objects and practices within and between individuals and communities did not produce perfect replications of metal objects and production practices and did not take place in societal isolation. The many small but observable variations tended not to be the consequence of imperfect copies or lack of understanding of the production techniques, but rather were founded on choices made by local individuals and communities based on existing cultural norms and desires. Whilst scholarship has naturally addressed the many technical aspects of metal production such as mining, smelting, alloying and working, the evidence indicates that the consumers of metal objects strongly influenced their production and final form. However, the knowledge of how to produce various metals and how to organise the production within a socio-economic system appears to have been shared across a vast territory. It is the responsibility of archaeometallurgists in the future to document these similarities and differences empirically. It remains a continuing quest to discern patterns of production and use so that we may come to understand better the role of metals and metalworkers in the growth of a trans-continental system of communication and exchange across Eurasia.

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