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On the origins of extractive metallurgy: new evidence from Europe

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A B S T R A C T

The beginnings of extractive metallurgy in Eurasia are contentious. The first cast copper objects in this region emerge c. 7000 years ago, and their production has been tentatively linked to centres in the Near East. This assumption, however, is not substantiated by evidence for copper smelting in those centres. Here, we present results from recent excavations from Belovode, a Vinča culture site in Eastern Serbia, which has provided the earliest direct evidence for copper smelting to date. The earliest copper smelting activities there took place c. 7000 years ago, contemporary with the emergence of the first cast copper objects. Through optical, chemical and provenance analyses of copper slag, minerals, ores and artefacts, we demonstrate the presence of an established metallurgical technology during this period, exploiting multiple sources for raw materials. These results extend the known record of copper smelting by more than half a millennium, with substantial implications. Extractive metallurgy occurs at a location far away from the Near East, challenging the traditional model of a single origin of metallurgy and reviving the possibility of multiple, independent inventions.

1. Introduction

The invention of extractive metallurgy, its location, timing, and origins, are among the restlessly argued matters in prehistoric archaeology. The introduction of metallurgy to prehistoric communities has provided an important chronological backbone for the later prehistory worldwide and has been widely discussed throughout the work of influential scholarship, and recognized as essential for the emergence of complex societies. Such ideas can be traced to the work of Childe (1944: 205, 209, 1958), who saw the Near Eastern prehistoric communities as the single inventors of extractive metallurgy. The concept of a single origin was challenged by Renfrew (1969) who argued for multiple inventions of metallurgy in independent centres throughout Eurasia. This debate has since received new field and analytical data, which helped understanding the geological, technological and/or social factors involved in various cultural manifestations of emerging metallurgical activity (cf. Roberts et al., 2009). However, due to the lack of direct evidence of actual smelting from any of the suggested regions of invention, the origins of extractive metallurgy remain hotly contested (Roberts et al., 2009; Thornton et al., 2010).

Importantly, in the studies of ancient metallurgy, metal artefacts have received the lion's share of the scholarly attention. The structural, chemical and isotopic analysis of artefacts can respectively show the ancient technology of their working and making, and the suggested geological origins of the metal used. However,

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the story of finished artefacts is only a relatively small part of the whole *chaîne opératoire* of metallurgy; a typical prehistoric metallurgical site would normally contain a set of various stone tools, ores, charcoal, fragments of technical ceramics and installations (furnaces, crucibles, tuyéres) and various types of slag and other waste products (cf. Rehren and Pernicka, 2008). For a more comprehensive understanding of the technology of metal production and its cultural transmission, the full range of technological debris needs to be analysed and incorporated in archaeometallurgical research (cf. Bachmann, 1982; Craddock, 1995 and literature therein, Renzi et al., 2009; Thornton and Rehren, 2009; Thornton et al., 2009).

This paper contributes to the debate on the origins of extractive metallurgy by presenting remains of copper smelting discovered recently in Belovode, a Vinča culture site in Eastern Serbia. Chemical, structural and provenance analyses of numerous finds including copper slag, geological and archaeological minerals, a copper metal droplet, and several malachite beads demonstrate consistent and coexisting metal smelting and malachite bead manufacturing activities at the site. Significantly, the analyses indicated that different sources were exploited for raw materials for copper smelting and bead making, respectively, suggesting a good knowledge of their relevant material properties. The first smelting event so far documented at Belovode occurs at c. 5000 BC, which makes it the earliest securely dated record of extractive metallurgy, anywhere. This event occurs at a location far from the Near East and in a region exceptionally rich in early metal artefacts, thereby challenging the model of a single origin of extractive metallurgy.

2. Development of copper metallurgy in Eurasia

The use of geological copper sources is known from two technologically rather independent industries: minerals such as native copper, malachite and azurite were used for millennia for bead and pigment making using ‘cold’ lithic technologies, before the ‘hot’ metallurgical production of copper metal by smelting/melting began. Indeed, the earliest interest in copper minerals was due to their distinctive optical properties: the use of green and blue beads and pigments goes back to the eleventh millennium BC, as documented from the Shanidar Cave in northern Iraq and Rosh Horesha in Israel (Bar-Yosef Mayer and Porat, 2008; Solecki et al., 2004). Close to the end of the 9th millennium BC, native copper was worked in Çayönü Tepesi in eastern Turkey, where metallographic analyses showed indications of annealing (Maddin et al., 1999). In the following millennia, copper mineral use became common among the prehistoric communities in the Near and Middle East. However, most of these objects were produced by cold working or using temperatures not exceeding a few hundred degrees Celsius. As such, they are firmly rooted in the technology of the Neolithic, which already included similar heat treatment of flint to improve its properties (Robins et al., 1978). This “cold” processing of minerals stands in stark contrast to the radical *change of material properties*, such as in smelting/melting events, and separates transformative, “hot” metallurgy from the manufacture of copper minerals into artefacts involving “cold” technologies such as carving, cutting, grinding, and hammering or rolling of native copper, as well as the lower temperature heat treatment mentioned above.

The first cast copper artefacts, dependent in their production on controlled temperature use exceeding 1000 °C emerge throughout Eurasia in the early 5th millennium BC (e.g. the copper chisel from Mersin layer XVI, Garstang, 1953; Yalçın, 2000; Yener, 2000), concurrent with the earliest European copper mining at Rudna Glava in Eastern Serbia (Borić, 2009; Jovanović, 1980). These artefacts appear almost a millennium earlier than the first known evidence for copper smelting in Jordan (Hauptmann, 2007) and Bulgaria (Ryndina et al., 1999). A possible exception is Tal-i Iblis in southeastern Iran, with numerous slagged crucible fragments from a large dump layer dated broadly between the late sixth and the late fifth millennium BC (Pigott, 1999).

At Çatal Höyük in Layer VI (dated to about 6500 BC) (Cessford, 2005: 69–70), Neuninger et al. (1964) reported ‘copper slag’, suggesting local processing of copper metal, but not necessarily its local smelting. Our interpretation of their detailed description of the relevant samples (Neuninger et al., 1964: 100–107) agrees with their identification of the non-magnetic copper oxide slag as dross, that is burnt metal, a typical by-product of metal melting and casting. The interpretation of the magnetic slag particles, not exceeding 4 mm in length, as possibly related to copper metallurgy is less clear. We agree with their identification of a limonitic core of these fragments, akin to gossan or other geological material, and a ‘hot’ outer skin reflecting sufficiently high temperatures to form rounded porosity, and possibly delafossite from the reaction of limonite and malachite. However, the small size of these particles and the limited penetration of the ‘hot’ zone into their core suggest a very short-lived thermal impact, not consistent with a well-mastered attempt to smelting. Although intentional heating could be suggested, in this context it is relevant to note that Layer VI is characterised by a large destructive fire (Mellaart, 1964: 115).

In Europe, researchers arguing for multiple origins of extractive metallurgy pointed to reports of copper smelting slag in Cerro Virtud in southeast Spain (Ruíz Taboada and Montero-Ruíz, 1999), questionably dated to the fifth millennium BC (Roberts, 2008), and the copious evidence for late sixth and fifth millennium BC copper ore mining in Rudna Glava and Ai Bunar, in the Balkans (Chernykh, 1978; Jovanović, 1971). The occurrence of the distinctive type of cast tools in this region during the early fifth millennium BC was cited as a strong indication for an independent metallurgical “industry” (Renfrew, 1969), hosted by several contemporaneous cultural groups, including the Vinča culture and the Kodžadermen-Gumelniţa-Karanovo cultural complex. Significantly, the surviving amount of copper circulating the Balkans throughout this period was estimated to about 4.7 tons altogether (Pernicka et al., 1997), which is equal to about 4300 copper implements. Noteworthy, the total number of contemporaneous cast copper artefacts in the entire Near East does not exceed three hundred (Ryndina, 2009). Such discrepancy led many to suggest a large-scale local production of copper in the Balkans. Firm support for this interpretation is provided by trace element and lead-isotope analyses (Pernicka et al., 1993) demonstrating that the copper artefacts from this region can be convincingly related to numerous ore deposits in Serbia and Bulgaria. However, actual smelting sites were lacking, which stifled an informed debate of their production origin.

3. Early copper smelting

The identification of early smelting evidence is fraught with difficulties. Craddock (1995, 2009) presents the idea of ‘slagless’ metallurgy based on very pure copper carbonate ores which, in principle, may leave virtually no slag, and summarises the evidence for the earliest European copper smelting with ‘slag heaps’ weighing in the tens of grams in total. Bourgarit (2007:10) further explores this concept arguing that “slagless” metallurgy usually occurs in domestic contexts, while the evidence for advanced control of the slagging process is usually found in more specialised Chalcolithic sites. This trend seems to continue even within the EBA, where mass production of metal stands in contrast to small -scale domestic production, reflecting different levels of organisation of metal production.