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Early Balkan Metallurgy: Origins, Evolution and Society, 6200–3700 BC

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Abstract

This paper analyses and re-evaluates current explanations and interpretations of the origins, development and societal context of metallurgy in the Balkans (c. 6200–3700 BC). The early metallurgy in this region encompasses the production, distribution and consumption of copper, gold, tin bronze, lead and silver. The paper draws upon a wide range of existing archaeometallurgical and archaeological data, the diversity and depth of which make the Balkans one of the most intensively investigated of all early metallurgical heartlands across the world. We focus specifically on the ongoing debates relating to (1) the independent invention and innovation of different metals and metal production techniques; (2) the analysis and interpretation of early metallurgical production cores and peripheries, and their collapses; and (3) the relationships between metals, metallurgy and society. We argue that metal production in the Balkans throughout this period reflects changes in the organisation of communities and their patterns of cooperation, rather than being the fundamental basis for the emergence of elites in an increasingly hierarchical society.

Keywords Metallurgy · Balkans · Invention · Innovation · Colour · Networks · Complexity · Community

Introduction

This paper analyses the evidence for early metallurgy in the Balkans from the earliest use of copper minerals at c. 6200 BC (Late Mesolithic–Early Neolithic) to c. 3700 BC (end of the Chalcolithic) (Figs. 1, 2, 3; except where stated otherwise all

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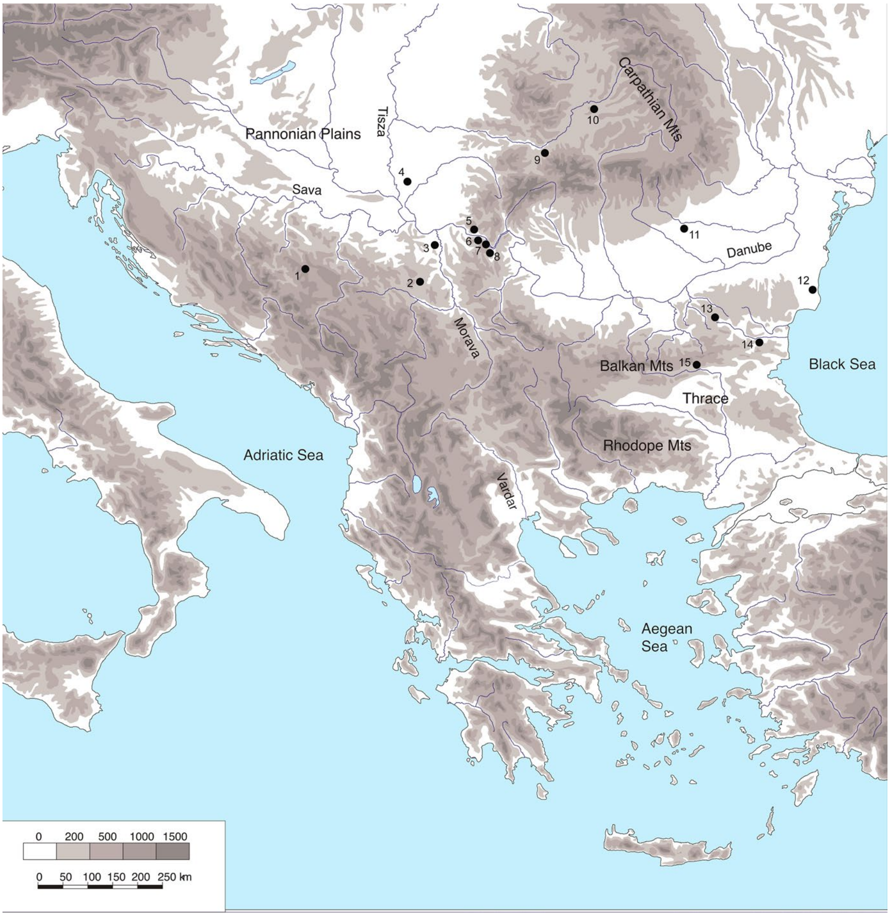

Fig. 1 Map of the Early Neolithic sites (c. 6200–5500 BC) mentioned here. 1: Obre I; 2: Divostin; 3: Zmajevac; 4: Szarvas 23; 5: Gornea; 6: Lepenski Vir; 7: Vlasac; 8: Rudna Glava; 9: Balomir; 10: Iernut; 11: Cernica; 12: Durankulak; 13: Ovcharovo I; 14: Usoe I; 15: Karanovo; 16: Kolubara-Jaričište. Map CC BY-NC-ND 4.0 J. Pendić and M. Radivojević

dates given here are based on calibrated radiocarbon values). Early metallurgy in this region encompasses the production, distribution and consumption of copper, gold, tin bronze, lead and silver, all being either in the form of pure metals or natural, self-alloying bronze (i.e. produced as a result of smelting complex ores—in this case, copper-tin-bearing ores—as opposed to having been deliberately produced by exposing two or more metallic elements to high temperature treatment through co-smelting, cementation or alloying of metals, ores, or metallic mixtures, such as speiss).

There are, arguably, a total of six major heartlands of early metallurgical invention and/or innovation in western Eurasia (Radivojević et al. 2010b), each of which is—not coincidentally—also geologically rich in copper mineral deposits with

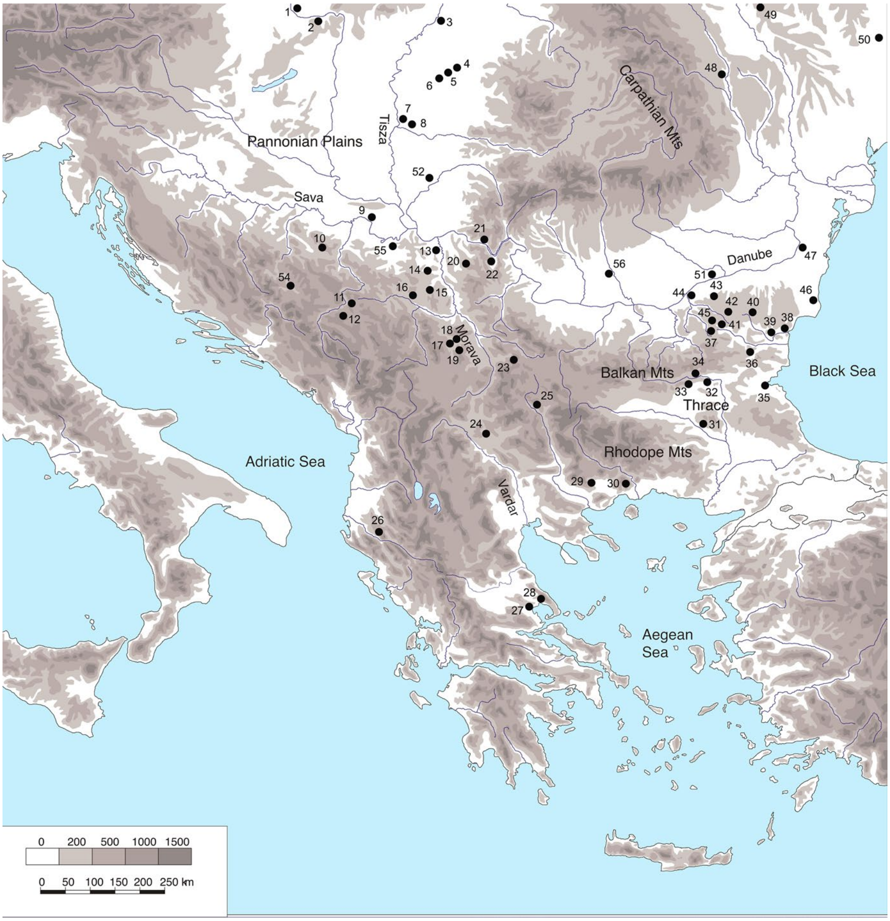

Fig. 2 Map of the Late Neolithic/Early Chalcolithic sites (c. 5500–4600 BC) mentioned here. 1: Mlynárce; 2: Neszmély; 3: Csöszhalom; 4: Hérpály; 5: Berettyószentmárton; 6: Zsáka-Markó; 7: Hódmezővársárhely-Kopáncs-Kökénydomb; 8: Gorsza; 9: Gomolava; 10: Gornja Tuzla; 11: Stapari; 12: Jarmovac; 13: Selevac; 14: Mali Šturac; 15: Divostin; 16: Ratina; 17: Pločnik; 18: Merovac; 19: Mačina; 20: Belovode; 21: Gornea; 22: Rudna Glava; 23: Hisarluka; 24: Anzabegovo; 25: Slatino; 26: Kamnik; 27: Dimini; 28: Sesklo; 29: Sitagroi; 30: Dikili Tash; 31: Maritsa; 32: Azmashka Mogila; 33: Ai Bunar; 34: Karanovo; 35: Medni Rid; 36: Golyamo Delchevo; 37: Targovište; 38: Varna; 39: Devnja; 40: Vinitsa; 41: Ovcharovo; 42: Radingrad; 43: Kubrat; 44: Ruse; 45: Polyanica; 46: Durankulak; 47: Cernavodă; 48: Izvoare I; 49: Lukavrublevetskaya; 50: Karbuna; 51: Pietrele; 52: Foeni; 53: Ždrelo; 54: Okolište; 55: Stubline; 56: Reșca (map CC BY-NC-ND 4.0 J. Pendić and M. Radivojević)

widespread surface expressions. In addition to the Balkans—our focus here—these are Iberia (Kunst, 2013; Montero Ruiz & Murillo-Barroso, 2016; Montero Ruiz et al. 2021), Anatolia (Lehner & Yener, 2014), the Levant (Golden, 2010; Klimscha, 2013), the Caucasus (Courcier, 2014), and Iran (Helwing, 2013; Thornton, 2009a). Currently the Balkans are perhaps the most intensively investigated of these, from both archaeological and archaeometallurgical perspectives (see papers in Roberts & Thornton, 2014). We recognise the different cultural, historical and geographical

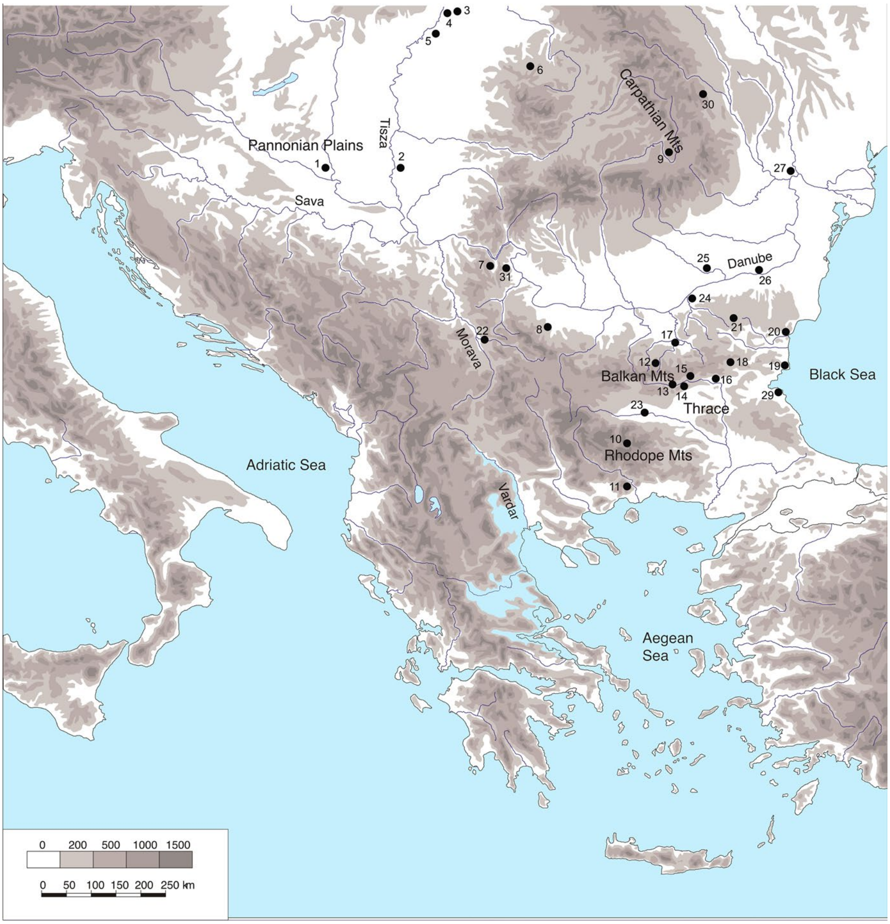

Fig. 3 Map of the Middle, Late and Final Chalcolithic sites (4600–3700 BC) mentioned here. 1: Zengővárkony; 2: Tiszapolgár-Basatanya; 3: Tibava; 4: Lucska; 5: Tiszapolgár–Hajdúnánás Road; 6: Moigrad; 7: Lazareva cave; 8: Gradeshnitsa; 9: Ariuşd; 10: Dolnoslav; 11: Dikili Tash; 12: Hotnica; 13: Bereketska Mogila; 14: Ai Bunar; 15: Karanovo; 16: Chatalka; 17: Kačica; 18: Smjadovo; 19: Kasla-–Dere; 20: Varna; 21: Kodžadermen; 22: Janka; 23: Mečkjur; 24: Ruse; 25: Vidra; 26: Gumelniţa; 27: Traian; 28: Alepotrypa Cave; 29: Akladi Cheiri; 30: Poduri; 31: Kmpije; 32: Bubanj (map CC BY-NC-ND 4.0 J. Pendić and M. Radivojević)

meanings of the widely-used term *Balkans* (Todorova, 1997) and the complex way these have influenced archaeological research (cf. Gori & Ivanova, 2017); for the purposes of this paper, while we use the term *Balkans* geopolitically as a region defined by the Adriatic Sea to the west, the Ionian and Aegean seas to the southeast and southwest, and the Black Sea to the east, we focus only on those sites that display evidence of mining and metal production and/or use during the indicated time frame. Observing current political divisions, we recognise such sites as located in Serbia, Bulgaria, Romania, Hungary, Bosnia and Herzegovina (BiH or, informally, Bosnia), Northern Macedonia, and Greece. Evidence of the heaviest concentration

Table 1 Relative and absolute chronology for cultures/archaeological complexes that exploited copper mineral (malachite) and/or were metal-using in the 'core' metallurgical zone (Serbia, Bulgaria, parts of Romania) between 6200 BC and 3700 BC. Chronological framework largely based on Schier (1996, 2014), Boyadžiev (1995, 2002) and Whittle et al. (2016). (*= use of copper minerals [i.e. malachite beads]; §= metallurgical materials [i.e. metal artefacts, slags])

Period	C14 dates	Vojvodina	Central Balkans	West Bulgaria	South Bulgaria	Muntenia	North-east Bulgaria	Black Sea Coast (west)
Proto Bronze Age	**3200**	Boleráz	Cernavoda III	**Galatin§**	**Yagodina§**	Cernavoda III	**Usatovo§**	Cernavoda I
Final Chalcolithic	**3700**	**Salcuța IV§** **Bodrogkeresztúr§**	**KSBh§**			Cernavoda I	**Cernavoda I/Pevets§**	
Late Chalcolithic	**4100**	**Tiszapolgár / KSBh§**		**Krivodol-Salcuța-Bubanj hum (KSBh) §**	**Karanovo VI§**	**Kodžadermen-Gumelnița-Karanovo VI§**	**Kodžadermen-Gumelnița-Karanovo VI§**	**Varna III§**
Middle Chalcolithic	**4450**	**Vinča D§**			**Marica IV§**	**Boian-Spanțov§**		**Varna I§** **Varna II§** **Hamangia IV§**
Early Chalcolithic	**4600**	**Vinča D§** **Vinča C§**		**Gradešnica§** **Dikilitash-Slatino§**	**Marica III§** **Karanovo V§**	Boian-Vidra	Poljanica	**Sava / Hamangia III§**
Late Neolithic	**5000**	**Vinča B*** **Vinča A***		Kurilo/Akropotamos Topolnica	Karanovo IV Karanovo III	Boian III	Hotnica	**Hamangia II*** **Hamangia I***
Early Neolithic	**5500** **6200**	**Starčevo*** **Lepenski Vir III***						

of metal production and consumption is present in the first four countries (see Figs. 1, 2, 3 and Table 1). However, due to the nature of the evidence and of the current debates, archaeological and archaeometallurgical research from surrounding geographical regions will also be referenced throughout this paper.

In bringing together current analysis of metallurgical and archaeological data from across the Balkans, we aim to re-examine three major questions that relate to metal in its global prehistoric context:

1. How did metallurgy in the Balkans develop?
2. Why did metallurgy emerge in the Balkans?
3. What was the relationship between early Balkan metallurgy and society?

These are classic and fundamental questions, and each is connected to its own deep history of scholarship and has produced answers in terms of a wide range of competing explanatory models. These questions are closely interrelated, and that they can now be re-evaluated is due to the application of an integrated science-based, theoretical and methodological approach that emphasises not simply the 'when' and the 'where' of early metallurgy but also the 'how' and the 'why'. This paper thus seeks to contribute to an emerging trend in archaeological and archaeometallurgical scholarship, highlighted by Thornton (2009b) as marking a paradigm shift in global early metallurgical scholarship (see the special double issue of the *Journal of World Prehistory*, volume 22 [2009]; Thornton & Roberts, 2009), subsequently expanded in Roberts and Thornton (2014). There is now an identifiable convergence in early metallurgy scholarship towards recognizing the need to define and analyse the theories and underlying evidence surrounding concepts of invention (see papers in Roberts & Radivojević, 2015) and innovation (e.g. Burmeister et al. 2013; Frieman, 2021; Maran & Stockhammer, 2017; Ottaway, 2001; Rosenstōck et al. 2016; Scharl, 2016). In addition, there is also a much stronger expectation of robust interpretation of phenomena, given that all the available evidence from the production cycle, from ore sources to finished objects and their eventual recycling, loss or deposition, is analysed using a more holistic approach (cf. Ottaway, 1994; Shimada, 2007), and that the results are then compared, contrasted and integrated with comparable analyses of contemporary craft production in other materials (Miller, 2005, 2007). Moreover, we are increasingly witnessing a much more critical assessment of the value of long-held Childean ideas regarding early metallurgy, including the claimed close association with emerging elites and major societal transformations (e.g. Bartelheim, 2007; Biehl & Marciniak, 2000; Chapman, 1991, 2020; Kienlin, 2010; Kienlin & Zimmermann, 2012; Lichardus 1991c; Porčić, 2012b, 2019).

Scholarship in Early Balkan Metallurgy

The subject of early metallurgy in the Balkans has attracted scholarly attention for almost a century and was closely associated with early twentieth century investigations of Vinča-Belo Brdo (Vasić 1932–1936), the eponymous settlement of the Vinča culture, c. 5400–4600 BC (Fig. 2); the discovery of metal artefacts at the tell settlement of Pločnik in south Serbia (Grbić, 1929); and the excavation of Vinča-style pottery in copper-mining shafts at Jarmovac in southwestern Serbia (Davies, 1937). The Balkan Peninsula, and specifically its northern part, subsequently became a major focus for scholarship concentrating on early mining and metallurgy as a result of four key developments or factors.

The first of these was the excavation of the copper mining sites Rudna Glava in Serbia and Ai Bunar in Bulgaria (Chernykh, 1978a; Jovanović, 1971, 1980, 1982), which were the subject of pioneering provenance studies (Pernicka et al. 1993, 1997). These two sites were identified as the cores of the Carpatho-Balkan Metallurgical Province (CBMP), an archaeometallurgical model which has been highly influential in the understanding of community interconnections across the Balkans and the Eurasian steppes (Chernykh & Kuzminykh, 1989; Chernykh et al. 2004; Chernykh, 1978b, 1992, 2013; Kohl, 2007; Koryakova & Epimakhov, 2007; Kuzmina, 2008; Yang et al. 2020). The abundance of copper deposits and the general richness of polymetallic veins across the Balkans has already been discussed at length as crucial for early access to minerals and experimentation. It is worth noting that, in the modern era, this rich metallogenic profile still supports a key industry in the region (e.g. Bogdanov, 1982; Janković, 1967, 1977, 1982; Jelenković et al. 2010; Monthel et al. 2002; Neubauer & Heinrich, 2003; Pernicka et al. 1993, 1997; Sillitoe, 1983).

The second development was the application of radiocarbon dating and, subsequently, archaeometallurgical research, which together revealed both the earliest known dates and the characteristics of copper metallurgy. Assessed against the evidence, this implied the independent invention of this technology in the Balkans (Glumac, 1991; Jovanović, 1980; Jovanović & Ottaway, 1976; Pernicka et al. 1997; Renfrew, 1969; Ryndina & Ravich, 2000, 2001; Todorova, 1978). The recent analysis of copper slag at the eastern Serbian Vinča culture site of Belovode, dating to c. 5000 BC (Radivojević & Kuzmanović-Cvetković, 2014; Radivojević & Rehren, 2016; Radivojević et al. 2010b; Radivojević, 2013, 2013b) served to reinvigorate the debate around the multiple inventions of metallurgy across Eurasia (see Montero Ruiz et al. 2021; Pearce, 2015; Pernicka, 2020; Radivojević, 2015; Roberts & Radivojević, 2015; Roberts et al. 2009; Rosenstock et al. 2016); in summary, however, we can now say that the Balkans have the earliest known evidence for the metallurgy of:

1. Lead, dating probably from the end of the 6th millennium BC (Radivojević & Kuzmanović-Cvetković, 2014) but occurring more regularly from the mid 5th millennium BC in the central Balkans (Glumac & Todd, 1987), and later in the eastern Balkans (Hansen et al. 2019);
2. Copper, from c. 5000 BC onwards in eastern Serbia (Radivojević & Kuzmanović-Cvetković, 2014; Radivojević & Rehren, 2016; Radivojević et al. 2010b; Radivojević, 2013, 2013b);
3. Gold, dating from c. 4650 BC onwards in eastern Bulgaria (Higham et al. 2007, 2018; Krauss et al. 2014, 2017; Leusch et al. 2014);
4. Bronze, from c. 4650 BC in southern Serbia and across Bulgaria (Chernykh, 1978b; Radivojević et al. 2013a, b, 2014a, b); and finally
5. Silver (probably) by the end of the 5th/early 4th millennium BC in Greece (Maran, 2000; Muhly, 2002), produced by cupellation (i.e. not originating in native silver in its rare, nugget form).

The third factor was the emergence and development of a distinctive and well-supported scholarly tradition, best exemplified by the *Prähistorische Bronzefunde* series, that focussed on the construction of detailed typo-chronologies for all the catalogued early metal objects, around four thousand three hundred in number. These objects, primarily copper implements, were then placed at the core of archaeological narratives concerning the prehistoric Balkans and its surrounding regions (e.g. Antonović, 2014; Chernykh, 1992; Diaconescu, 2014; Driehaus, 1952–1955; Govedarica, 2001; Heeb, 2014; Kuna, 1981; Patay, 1984; Ryndina, 2009; Schubert, 1965; Taylor, 1999; Todorova, 1981; Vulpe, 1975; Žeravica, 1993).

The fourth and final development was the discovery, excavation, publication, and high-profile exhibition of the fifth millennium BC cemetery at Varna in Bulgaria, with its spectacular metallic grave inclusions (still unparalleled in volume by any other single site). Varna became central to the ongoing major debates relating to the existence (or non-existence) of elites, and the dynamics of apparent inequality, in the 5th and 4th millennia BC (e.g. Biehl & Marciniak, 2000; Chapman, 1991, 2013; Chapman et al. 2006; Crnobrnja, 2011; Fol and Lichardus, 1988; Hansen, 2013a; Higham et al. 2018; Ivanov, 1978b; Klimscha, 2014, 2020; Krauss et al. 2017; Leusch et al. 2017; Müller, 2012; Porčić, 2012b, 2019; Reingruber, 2014; Renfrew, 1978, 1986; Slavchev 2008).

With these four factors in mind, we can say that it is still the case that in Balkan prehistory metallurgy is understood mostly through the presence of copper mining and the typology and distribution of metal artefacts (mainly copper and gold), although such information reflects only the two extreme ends of the metal production process or cycle. Production debris such as slags and crucibles, despite its rarity (and infrequent recovery in the field or subsequent analysis) in the archaeological record of the Chalcolithic, is far more informative about the metalmaking recipes, and the transmission of metallurgical knowledge or ore provenance, than the morphology of the final products or their metallic origins (cf. Hauptmann, 2014; Killick, 2014; Martinón-Torres & Rehren, 2008, 2014; Rehren, 2003, 2008; Rehren et al. 2007). Slag, a by-product of metal extraction, is a vitreous, usually amorphous and highly magnetic material that typically contains traces of all components contributing to its formation while remaining largely resistant to post-depositional processes and dislocation (Bachmann, 1982). Slags can be found as free pieces but also attached to the walls of crucibles, furnaces, or slagged sherds, as is the case for early metal production in the Balkans (Radivojević & Rehren, 2016).

It should be noted that the deteriorating political situation in the Balkans from the 1990s onward, in the aftermath of the collapse of communism, hugely disrupted many early metal-orientated archaeological and archaeometallurgical research projects. The negative impact on fieldwork, publication and collaboration has been reversed only relatively recently, as evidenced by the successful growth of the Balkan Early Metallurgy Symposia (BEMS) meetings in London, UK (2007); Prokuplje, Serbia (2010); Sozopol, Bulgaria (2013) and Târgu Jiu, Romania (2015). This upsurge can also be seen in the continued prominence of metallurgical research within the festschrifts of major Neolithic–Copper Age Balkan archaeologists whose students and colleagues now occupy prominent positions in archaeological museums, university departments and research institutes (e.g. Forţiu & Cîntar, 2014; Stefanovich & Angelova, 2007; Ţerna & Govedarica, 2016). Metal-orientated scholarship is also very evident, not simply in the classic and still influential conference proceedings published *as Die Kupferzeit als Historische Epoche* (Lichardus, 1991b), but also in more recent proceedings from the three major international conferences published on the region: *The Neolithic and Eneolithic in Southeast Europe* (Schier & Draşovean, 2014); *Neolithic and Copper Age between the Carpathians and the Aegean Sea: Chronologies and Technologies from the 6th to the 4th Millennium BC* (Hansen et al. 2015); and *Der Schwarzmeerraum vom Neolithikum bis in die Früheisenzeit (6000–600 V. Chr)* (Schier and Nikolov 2016). All reflect the depth and influence of German scholarship—and the increasing use of English in publications.

It is therefore not surprising that, despite the rapid growth of settlement, landscape and environmental research and perspectives, interpretations of the life of prehistoric Balkan communities (and especially those of the 5th millennium BC) have been frequently influenced by the conventional, metal-orientated approaches in archaeological research in the area. These are derived from the seductive idea that the presence of craft specialisation indicated the presence of a complex social organisation (Childe, 1950), and that metal technology is tightly correlated with an increase in social complexity (e.g. Childe, 1944; Morgan, 1985 [1877]; White, 1959). This notion led to the pursuit of evidence for centralised decision making in any society with metallurgical practice. In turn, it made the Balkan case, with the earliest traces of metal making and the earliest large scale production and circulation of metal ornaments and implements, central to arguments concerning the advent of highly specialised knowledge in combination with the accumulation of individual wealth and emerging social hierarchy (e.g. Hansen, 2013b; Renfrew, 1978, 1986).

This metal construct is still frequently dominant in scholarship seeking to define the (elite) socio-economic dynamics of prehistoric communities, despite the fact that other materials such as ceramics, flint, polished stone, obsidian and spondylus (e.g. Amicone et al. 2019; Amicone et al. 2020a; Amicone et al. 2020b; Ifantidis & Nikolaidou, 2011; Klimscha, 2016; Milić, 2015; Spataro, 2018; Whittle et al. 2016; Windler 2018) were also comparably, or much more extensively, sourced, shaped, traded and/or deposited in settlements and graves both prior to and, later, along with metal objects. It is evident that, especially in the last decade, many major Balkan Neolithic/Chalcolithic projects have explicitly sought to push beyond traditional metal-orientated perspectives, especially given the significantly increased scale and depth of understanding of the non-metallurgical archaeological andenvironmental record in recent years. This is reflected in recent syntheses, whether encompassing the Balkans (Chapman, 2020) or the Black Sea region (Ivanova, 2013). In particular, research engaging with population dynamics, subsistence strategies, settlement practices, and responses to local and regional environmental and climatic change is thriving (e.g. Benecke et al. 2013; Chapman & Souvatzi, 2020; Filipović et al. 2017, 2018; Gaastra et al. 2018; Ivanova, 2012, 2020; Ivanova et al. 2018; Marić, 2013, 2015, 2017; Müller, 2012; Orton, 2010, 2017; Orton et al. 2016; Porčić et al. 2016; Porčić, 2011, 2012b, 2020; Silva & Vander Linden, 2017). It is also worth noting that several major, modern excavation and survey projects of Neolithic–Chalcolithic sites in the Balkans, such as Okolište (Bosnia), Uivar (Romania), and Vinča (Serbia) (Draşovean et al. 2017; Müller, 2013; Schier, 2014b; Tasić et al. 2016), have yet to document substantial metal objects or any clear evidence for metal production. However, where metal objects and/or metallurgical remains are found, as at Pietrele (Romania) (Hansen & Toderaş, 2012; Hansen et al. 2019), familiar interpretative narratives relating to metals and elites are proposed (Hansen, 2012, 2013a; Klimscha, 2020). The primary challenge, at least at the broader interpretative scale, in investigating the origins, development and societal inter-relationships of early metal objects and metallurgy in the Balkans, is to analyse and interpret the metal-orientated evidence, not in technological or intellectual isolation, but in relation to the other practices and activities of communities living in the region in the Late Neolithic and throughout the Chalcolithic (c. 6200–3700 BC).

Chronological Frameworks of Balkan Early Mineral and Metal Use, c. 6200–3700 BC

The relative chronological frameworks spanning the Balkans during the absolute date range of this paper (c. 6200–3700 BC) are notoriously complex, largely due to the accumulation of over a century of scholarly traditions that have varied significantly from country to country. In order to avoid confusion, the period related to the emergence of metallurgy throughout southeast Europe is referred to here as the *Chalcolithic*, in preference to either the *Eneolithic* (as used in the former Yugoslavia and Romania) or the *Copper Age* (as used in Hungary). The potential for confusion is especially pertinent to the term *Eneolithic*, used by archaeologists in the former Yugoslavia to refer to a period starting with the beginning of the use of metals from the mid–late 5th millennium BC; for Bulgarian archaeologists, this correlates with the Middle-to-Late Chalcolithic, when metals had already been widespread for centuries (e.g. Todorova, 1995). To facilitate navigation through the various labels used by Balkan archaeologists for the same phenomenon, we follow the Chalcolithic periodisation in the Balkans (Early, Middle, Late and Final) as it has been elaborated by Bulgarian scholars (see below).

The application of radiocarbon dating in the past few decades with, more recently, Bayesian statistics, has significantly influenced and strengthened the independent and relative temporal frameworks for Balkan prehistory between c. 6200 BC and 3700 BC (e.g. Bojadžiev, 2002; Forenbaher, 1993; Georgieva, 2012; Görsdorf & Bojadžiev, 1996; Higham et al. 2007, 2018; Krauss, 2008; Krauss et al. 2014, 2017; Lazarovici, 2006; Luca, 1999; Müller et al. 2013; Orton, 2017; Patay, 1974; Pernicka et al. 1993, 1997; Radivojević et al. 2010b; Schier, 1996, 2014a; Todorova, 1981, 1995; Vander Linden et al. 2014; Weninger et al. 2009; Whittle et al. 2016). This is especially true of recent intensive radiocarbon dating and Bayesian modelling of entire stratigraphic sequences at selected, well-excavated sites. Major radiocarbon dating projects across Neolithic Europe led by Alasdair Whittle (Whittle et al. 2002, 2016, 2018) have encompassed the sequences of the Balkan Neolithic–Chalcolithic Age sites of Uivar in Romania and Vinča-Belo Brdo in Serbia (Draşovean et al. 2017; Tasić et al. 2015, 2016). A further radiocarbon dating project across Late Neolithic–Early Bronze Age Greece and Bulgaria led by Zoï Tsirtsoni has also been recently completed (Tsirtsoni 2016b). These two major projects are further complemented by a range of smaller radiocarbon dating projects at specific sites, such as Belovode and Pločnik in Serbia (Radivojević & Kuzmanović-Cvetković, 2014; Radivojević et al. 2010b; Radivojević et al. in press). However, extensive radiocarbon dating remains absent at the majority of late 7th to early 4th millennium BC sites and, invariably, at potential copper mining sites and depositions of metal objects, right across the Balkans. It is still, therefore, the relative chronological frameworks based on ceramic types, and the traditional archaeological culture units—most of them identified a century ago—whose absolute date ranges are constantly being refined, as recently with Vinča culture ceramics (cf. Whittle et al. 2016). Further, the emergence in the twentieth century of rival national traditions of archaeological scholarship across the Balkans has frequently meant that virtually identical archaeological phenomena whose distribution crosses modern national borders have been assigned different nomenclatures, as in the case of the Starčevo-Criş-Körös cultural complex, where *Körös* and *Criş* are two names for the same river after which an Early Neolithic cultural phenomenon was named in Hungarian and Romanian respectively, while *Starčevo* refers to the down-river type site in northern Serbia. As a result, regional scholarship has been tasked with identifying the connections between these culture-historical sequences and then proposing new nomenclatures that integrate the pre-existing terms.

It is therefore not uncommon to see debates on the connections between the emergence of metallurgy and the Gradac phase of Vinča culture ceramic sequence, or the relationship between the development of metallurgy and the widespread graphite painted decoration on the ceramics of the Kodžadermen–Gumelniţa–Karanovo (KGK) IV cultural complex (e.g. Amicone et al. 2019, 2020b; Garašanin, 1995; Jovanović, 1971, 1994, 2006; Radivojević & Kuzmanović-Cvetković, 2014; Radivojević et al. 2010b; Renfrew, 1969; Spataro & Furholt, 2020; Spataro et al. 2019; Todorova, 1995; Todorova & Vajsov, 1993). As is now widely acknowledged in Balkan and world prehistory, the creation of spatial and temporal frameworks through the identification of similarities and differences in materials and practices continues to evade researchers; straightforward explanations are unlikely (cf. Gori & Ivanova, 2017; Roberts & Vander Linden, 2011; Shennan, 2013). It would seem inevitable that, despite well-argued proposals for abandoning relative typologies and cultures in the Balkans due to increased availability of improved independent scientific dating techniques (Tsirtsoni, 2016b), they will endure into future generations of archaeological scholarship.

The major interpretative problem that this creates with regards to early metallurgy is the need to connect a scientifically-based metallurgical practice or sequence with the pre-existing and convoluted culture-historical framework. The consequence is that an archaeological culture (now implicitly rather than explicitly related to a vaguely defined, large population group) becomes ‘metal producers’ and/or ‘metal consumers’, along with the intellectual baggage outlined above. The persistent influence of the culture-historical paradigm hampers the ability of metallurgical data, both old and new, to make an independent contribution to understandings of social and economic phenomena in the periods and regions under review.

Despite this less than ideal starting point, the recent application of complex network analyses to the chemical data of more than four hundred copper-based objects from 79 archaeological sites across the 7th to the 4th millennium BC in the Balkans has enabled the creation of statistically significant models of interconnections that are independent of traditional culture-chronologies (Grujić and Radivojević in press; Radivojević & Grujić, 2018). These not only enable pre-existing spatial and temporal cultural frameworks to be exposed to scrutiny, but also produce identifiable patterns of community interactions and cooperation whose changes through time can be investigated (see below). Importantly, the complex networks approach has engendered an interest in expanding the current compositional dataset of copper objects beyond the territories of modern-day Serbia, Bulgaria, and Bosnia-Herzegovina, and into Romania (e.g. Lazar et al. 2019; Stefan, 2008).

While the complex networks approach continues to develop, for the purposes of this paper we use the available relative and absolute dating, spanning c. 6200–3700

BC throughout the Balkans. We identify six periods, reflecting the changing characteristics of the metallurgical evidence, which enable questions surrounding metallurgical origins, development and societal inter-relationships to be addressed. These are: *Early Neolithic* (c. 6200–5500 BC); *Late Neolithic* (c. 5500–5000 BC); *Early Chalcolithic* (c. 5000–4600 BC); *Middle Chalcolithic* (c. 4600–4450 BC); *Late Chalcolithic* (c. 4450–4100 BC); and *Final Chalcolithic* (c. 4100–3700 BC). It should be stressed, however, that in certain areas the limited level of published and modern excavation makes it hard to evaluate the framework, as neither the radiocarbon-dating framework nor the available archaeometallurgical data are adequate. Our strongest focus remains, therefore, on the modern-day territories of Serbia, Bulgaria, Romania and Hungary (see Figs. 1, 2, 3), as the core area of activities related to mineral use and metallurgy. The majority of the period-definitions used to construct the chronological scheme for this article have been employed in earlier frameworks. The identification of a new 150-year period, spanning the mid 5th millennium BC (c. 4600–4450 BC: *Middle Chalcolithic*), reflects recent dating and current interpretations centred on the iconic—and still unparalleled—site of Varna, Bulgaria. One possibility here is that the site reflects a relatively short regional phenomenon, encompassing distinctive metal production and consumption evidenced by a growth in wealth (e.g. Biehl & Marciniak, 2000; Chapman, 2013; Schier, 2014a), although other factors may also have had a role.

The extensive programmes of radiocarbon dating at Varna placing activities there between 4690 and 4330 BC (e.g. Higham et al., 2007, 2018; Krauss et al., 2017) have ensured that it is one of the most accurately-dated of all Chalcolithic sites in the Balkans at which evidence of metal production or metal objects have been found. Furthermore, the recent identification of a tin bronze object dating to c. 4650 BC at Pločnik, Serbia (Radivojević et al., 2013a, b) also appears to be the product of a distinct phase that may relate metals to the emerging socio-economic networks and community relationships across the eastern and central Balkans. The major changes in copper sources that occur during the mid 5th millennium BC (see networks section below), and the potential presence of contemporary silver objects, taken together with the evidence for gold and tin bronze, all suggest that further programmes of dating and analysis should explore the possibility of a technologically distinct and short-lived polymetallic horizon.

How and Why Did Metallurgy Emerge in the Balkans?

The possibility of being able to establish the origin of a defined phenomenon in prehistoric archaeology can be powerfully motivating, but as Clive Gamble suggested when he coined his playful concept of 'Originsland' (Gamble, 2007), it is usually more about imagination than actual evidence. While the present authors have argued elsewhere that an exception should be made for certain pyrotechnologies where preserved processes of invention and innovation might be analysed and identified (see papers in Roberts & Radivojević, 2015), we acknowledge that questions of origins are rarely straightforward. Scholarship debating the origins of metallurgy in the Balkans dates to the early antiquarian period in the mid 19th to the early 20th century

(Childe, 1944; Grbić, 1929; Von de Pulsky, 1884), and consistently equated technological advancement, as expressed through evidence of pyrotechnological abilities, with temporal and societal change (see also reviews by Pearce, 2019; Schier, 2014a). This model also acknowledged the unique historical circumstances that may have dictated variations in the dynamics of innovations, and in their adoption and adaptation (Childe, 1951). The mid-to-late twentieth century saw the emergence of two highly influential opposing ideas that still structure many discussions. The first argued for the introduction of metallurgy to the Balkans by an external population group – that is, by archaeological cultures in-migrating from the east (e.g. Childe, 1929; Garašanin, 1973). The second was the identification of indigenous metal-using communities considered to represent the emergence of new Copper Age, Chalcolithic or Eneolithic societies at a local level in the Balkans (e.g. Gimbutas, 1980; Jovanović, 1971; Lichardus, 1991; Renfrew, 1969c). The debates surrounding the origin of metallurgy in the Balkans and Anatolia/Near East divided scholars into advocates of either independent invention or of migration/diffusion (see Bognár-Kutzián, 1976 for a summary). The perceived importance of the issues prompted some of the earliest applications of radiocarbon dating in world archaeology, and these were used to challenge the various *Ex Oriente Lux* interpretations with a model of independent invention (Jovanović & Ottaway, 1976; Renfrew, 1969, 1970; *contra* Wertime, 1964, 1973). Although highly controversial at the time (Makkay, 1976, p. 263), the overall temporal framework indicated by the early radiocarbon dates has now become widely accepted.

The independent invention model for Balkan metallurgy was subsequently further strengthened through various research initiatives and methodological advances. These included: assessment of the quantity, typology and metallurgy of cast shaft-hole axes (Charles, 1969); calibration of the new radiocarbon dates using dendrochronology (Renfrew, 1973); and stratigraphical observations at the excavations at Sitagroi (Greece; Fig. 2) that showed that the Serbian Vinča culture preceded the Early Bronze Age of Anatolia (i.e. Troy I) by more than two millennia (Renfrew, 1979, p. 139). Further supporting evidence accumulated during the 1970s, with the excavation and dating of copper mines at Ai Bunar (Chernykh, 1978a, 2008a) and the discovery of substantial numbers of gold and copper objects at the cemetery of Varna in Bulgaria (Ivanov & Avramova, 2000; Ivanov, 1978b). The '*Ex Balcanae Lux*' model (Todorova, 1978) represented a new paradigm and caused a widespread re-appraisal of the origins of early technologies in the region (see Sterud et al., 1984 for a summary). As Thornton (2001) dryly noted, the major advocates for an independent invention of southeastern European metallurgy were also the most adamant diffusionists when it came to the spread of Neolithic subsistence practices and the origins of the Indo-European language zone (Gimbutas, 1973; Renfrew, 1987).

In addition to dominating the agenda for the 'when' and 'where' for the origins of metallurgy, Renfrew's (1969) suggestion of a direct connection between the production of graphite-painted ceramics and the invention of copper metallurgy also provided a new explanatory framework for the 'how'. His pyrotechnological transfer model was subsequently also advocated by Gimbutas (1976), although it was not to be investigated from a comparative pyrotechnological perspective until nearly four decades later (Amicone, 2017; Amicone et al., 2020b). A partial model for the ‘why’ that went beyond the back-projection of assumed ideas concerning value (e.g. Renfrew’s ‘prime value’ concept for gold: Renfrew, 1986) and the innate desirability of metals, as used by advocates both of independent invention and diffusion, was provided by Glumac (1991). Glumac made the connection between the use of ores for decoration and early metal use in the context of the Balkans—an approach subsequently extended across Anatolia and the Near East by Thornton (2001). The early use, across the Starčevo and (subsequently) early Vinča occupation horizons, of specific types of copper minerals (black-and-green manganese-rich copper carbonates) that were later smelted to produce the earliest known copper metal, has most recently been shown to be a unique technological trait of Balkan metallurgy, and further reinforces the idea that an independent invention of metal making took place here, even if symbolic practices involving the decorative use of metallic minerals had previously diffused in from the Near East (Radivojević et al., 2010b; Radivojević, 2013a, b, 2015).

There are consequently three definable, yet partially interrelated, models for the origins of metallurgy in the Balkans. All are primarily focussed on copper minerals/ores (rather than gold, tin bronze or lead) and the ambiguous relationship with ceramic pyrotechnology. Underlying each of these models are the motivations of the people involved in identifying, selecting and smelting copper ores and their knowledge of and relationship with pre-existing pyrotechnologies.

These models are:

1. The migration of individuals and groups from the east with the necessary knowledge of the selection of copper minerals/ores, and expertise in pyrotechnology;
2. The transmission, via existing socio-economic networks, of knowledge and expertise relating to copper ores, copper minerals and pyrotechnology from the east into communities in the Balkans;
3. The independent invention of metallurgy by communities in the Balkans who exploited the rich abundance of copper minerals and their knowledge of them and, through time, adapted their pyrotechnological expertise to smelt metal.

The three models can be evaluated against established data as well as recent research leading up to and including the *Rise of Metallurgy in Eurasia* project (Radivojević et al. in press). Each of the models will be evaluated below, looking at both the Early Neolithic (c. 6200–5500 BC) and the Late Neolithic (c. 5500–5000 BC).

Mineral and Ore Selection

Copper *minerals* in the archaeological record are not necessarily copper ores. Ore is a culturally-defined concept, referring to agglomerations of minerals from which the extraction of one or more metals is seen as a profitable action, and in pre-industrial times criteria of profitability may have been different (e.g. Radivojević & Rehren, 2016; Rapp, 2009; Rehren, 1997). In other words, what the modern mining industry considers the economically feasible exploitation of mineral resources today differs from what prehistoric miners saw as an acceptable investment of labour. Put simply, if a mineral is smelted then it can be considered to have been an ore. The significance of this distinction in the context of metallurgical activities has been raised by Muhly (1989), who compared the relationship of malachite (copper carbonate) and copper metallurgy at an archaeological site to that of haematite (iron oxide) in a cave painting and iron metallurgy. Muhly's point was that, just as Palaeolithic cave painters were not making iron, and had other reasons for collecting ochre, the presence of malachite manuports in prehistoric contexts should not be seen only in direct relation to copper metallurgy. This distinction between the use of copper minerals and smelting of copper ores is of immense importance in understanding the economic value ascribed to raw materials used for making copper metal. It nonetheless remains fundamentally important to record the presence of copper minerals and ores, especially within the context of debates regarding early metallurgy.

The earliest evidence for the use of copper minerals in the Balkans occurs during the transition to the Early Neolithic (or the emergence of Starčevo-Criş-Körös culture groups) in c. 6200–5500 BC, with evidence spanning the Carpathian Basin, Moldavia, western Ukraine and northern Balkans (Bognár-Kutzián, 1976, pp. 70–73). The earliest exploitation of copper minerals was possibly by hunter-fisher-gatherer communities (likely mixed with the early farming population migrating from Anatolia; see, for instance, Mathieson et al. 2018). This is indicated by samples discovered at Lepenski Vir, Vlasac and Kolubara-Jaričište (Fig. 1) and dated to c. 6200 BC (Radivojević, 2015: 325; Srejović & Letica, 1978, pp. 11–14). The processing of copper minerals and native copper developed within the subsequent Neolithic Starčevo-Criş-Körös culture groups; these groups mostly produced beads from malachite [$Cu_2CO_3(OH)_2$] or azurite [$Cu_3(CO_3)_2(OH)_2$]. In addition to malachite and azurite beads from Lepenski Vir and Divostin I (Glumac, 1988, p. 460; Radivojević, 2012; Srejović, 1969, p. 173; 1972, p. 146), similar items were found in the cemeteries of Cernica in southern Romania and Durankulak in north-eastern Bulgaria, and the settlements of Obre I in Bosnia, and Ovcharovo I and Usoe I in Bulgaria (Cantacuzino & Morintz, 1963, pp. 72–75, fig. 28: 18, 19; Pernicka et al. 1997, p. 44; Sterud & Sterud, 1974, p. 258; Stratton et al. 2019; Todorova, 1981, p. 4; Vlassa, 1967). Lumps and flakes of copper minerals were also identified in the settlements of Zmajevac in eastern Serbia and at Szarvas 23 in Hungary (cf. Bailey, 2000, p. 210; Chapman, 1981, p. 131; Chapman & Tylecote, 1983, p. 375; Comşa, 1991, p. 51; Fig. 1). Malachite beads and copper minerals are also commonly found in early Vinča culture settlements (pre-5000 BC) at the sites of Belovode, Pločnik, Vinča-Belo Brdo, Selevac and Medvednjak (Fig. 2), and occur continually until the abandonment of the settlements, as well as throughout other, later Vinča culture manifestations, such as Gomolava (Glumac & Tringham, 1990; Radivojević, 2012; Radivojević & Kuzmanović-Cvetković, 2014; Šljivar 1993–2009; Šljivar and Kuzmanović-Cvetković 1996–2009). At the sites of Belovode and Pločnik, also excavated by the authors of this article (Radivojević et al. in press), green malachite was found in every excavation spit, every feature, and every defined horizon; it was dispersed across the excavated areas, at times without an obvious spatial pattern, although much more frequently in the later stages of the occupation of each site (post-5000 BC). Significantly, at Divostin II (Vinča D phase), malachite beads were predominantly found in a group of rather large houses, where a metal bracelet was also present (McPherron & Srejović, 1988). The beads and bracelet were interpreted as a possible indication of the higher status of the occupants, on the basis that larger households would have a larger labour force available to create a surplus and therefore an economic advantage (Porčić, 2012b).

The provenance analyses of most of the minerals found at Lepenski Vir, Vlasac and the Vinča culture sites indicated the use of local sources, predominantly Majdanpek in eastern Serbia, then Ždrelo (near Belovode; Fig. 2), and an as yet unidentified copper source consistent with most of the Pločnik minerals and metal artefacts and copper slags from Belovode (Pernicka et al. 1993, p. 6; 1997, p. 93 ff.; Radivojević, 2012; Radivojević et al. 2010b, p. 2784; Fig. 10). The only securely dated source where there is evidence for copper mineral exploitation within this period is at the site of Rudna Glava, in Serbia (Fig. 2), where copper mining activities intensify from c. 5500 BC in parallel with copper mineral use at nearby Belovode (O'Brien, 2015; Radivojević & Kuzmanović-Cvetković, 2014). Importantly, the inhabitants of this site appear to have distinguished between pure green copper minerals (malachite) as a resource suitable for bead making (hence bead minerals) and what they may have considered 'tainted' manganese-rich black-and-green copper ores, used for the smelting charge (Fig. 4a). This supposition is strengthened by the identification of distinctively different lead isotope signatures for the bead minerals and ores smelted at Belovode, indicating existing knowledge of the different properties of these materials (Radivojević et al. 2010b, p. 2784). A similar practice of differentiation between pure green copper minerals and black-and-green manganese-rich copper ores has been detected throughout the Vinča occupation at the sites of Vinča-Belo Brdo and Pločnik (Fig. 2), indicating an awareness of the material properties of these distinctive copper occurrences for around eight hundred years across all these settlements (Radivojević & Rehren, 2016, p. 215).

Artefacts made of native copper appear in the Balkans only at the start of the Late Neolithic (c. 5500–5000 BC), but most have been only relatively dated and their cultural provenience is debatable. One out of three such artefacts, a fragmented copper object from Iernut (Horedt, 1976; Lazarovici, 1979, 2014; Mareş, 2002), a site located deep in the Carpathian Mountains in Romania (Fig. 1), has been ascribed to the last phase of the Starčevo-Criş-Körös phenomenon (mid 6th millennium BC). A 14 cm-long double pointed awl, discovered at the site of Balomir (Fig. 1) is the earliest identified implement made of native copper in the Balkans (Vlassa, 1967, pp. 407, 423; Fig. 6). It is relatively dated to the mid 6th millennium BC, around the same time as a fish hook from the site of Gornea in the Danube Gorges (Lazarovici, 1970, p. 477). While it is challenging to distinguish between the use of native copper and metal made from smelted copper ores, Pernicka (1990) argues that increased concentrations of cobalt (Co) and nickel (Ni) are a useful indicator of copper artefacts made of smelted copper. Pernicka synthesised Balkan and Anatolian copper metal artefact trace element data and compared these to the analyses of native copper from these same regions. The Co and Ni concentrations in native copper (approximately < 20 ppm) are extremely low in comparison to the much higher concentrations of these elements in both Balkan and Anatolian copper metal artefacts (Pernicka et al. 1997, pp. 124, 159–160, fig. 23, table A3a). Interestingly, a few

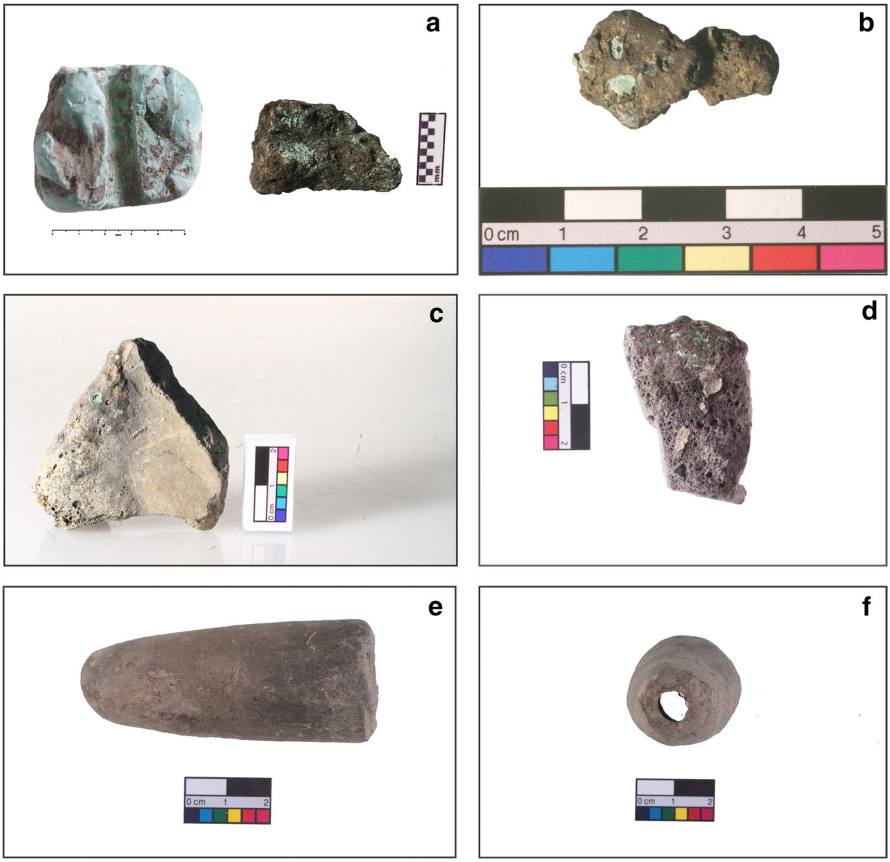

Fig. 4 Copper mineral and metallurgical evidence from mid 6th–mid 5th millennium BC. **a** typical malachite bead on the left and a black-and-green mineral on the right (Belovode); **b** copper slag from Belovode; **c** ceramic sherd with copper slag overflowing its top, most likely used to line a hole-in-the-ground smelting installation (Belovode); **d** ceramic sherd with copper slag (Foeni); **e** & **f** ceramic nozzle, potentially used for (s)melting (Bubanj, see also in Bulatović, 2015) (adapted after Radivojević, 2012; CC BY-NC-ND 4.0 M. Radivojević and Lj. Radivojević)

copper implements from Pločnik show borderline concentrations of Co and Ni (Pernicka et al. 1997, pp. 147–148, table A1), which might indicate a native copper origin. There is no evidence for the exploitation of native gold or silver in this period, despite the geological potential throughout the Balkans (e.g. Jovanović, 2001).

Evidence suggests that use of copper mineral and native copper in neighbouring Anatolia and the Near East occurred much earlier than in the Balkans. The earliest example dates back to the 11th millennium BC Epipalaeolithic burial site of Shanidar Cave, where a malachite bead was deposited as a grave offering (Bar-Yosef, 2008; Solecki et al. 2004, p. 96). By the 9th millennium BC, native copper and copper minerals were increasingly worked, as at the settlement of Çayönü Tepesi in eastern Turkey, a site which also yielded evidence for the annealing of native copper

(Maddin et al. 1999; Özdoğan & Özdoğan, 1999). This settlement was conveniently located near the rich copper mineralisation outcrop of Ergani Maden, but the prehistoric exploitation of this source has not yet been demonstrated. By 6000 BC, the use of copper minerals spreads beyond its 'core' zone in Anatolia and northern Mesopotamia to the Levant (Golden, 2010), Transcaucasia (Courcier, 2014; Kavtaradze, 1999), the Balkans (Glumac & Tringham, 1990; Thornton, 2001; see below), Iran (Helwing, 2013; Pigott, 1999; Thornton, 2009), and Pakistan (Hoffmann & Miller, 2014; Kenoyer & Miller, 1999). The strong association of intensive copper mineral use and agriculture is apparent, and has been explained by Bar-Yosef Mayer and Porat (2008) as inherently related to the powerful symbolism of the colour green in relation to crop fertility. Their study also showed that copper minerals were not the only 'green' option for the Near Eastern (Pre)Neolithic communities, since ornaments made of apatite, turquoise, amazonite or serpentinite were also made, valued presumably primarily for their visual properties (Bar-Yosef Mayer & Porat, 2008, p. 8549, table 1).

Balkan–Anatolian Connections and Pyrotechnology

It is beyond doubt that the practice of using green minerals was transmitted to the Balkans from Anatolia, particularly given its association with early agricultural communities and attested migration movements (e.g. Ammerman & Cavalli-Sforza, 1971; Furholt, 2017; Mathieson et al. 2018; Racimo et al. 2020; Rosenstock et al. 2016; Shennan, 2018; Silva & Vander Linden, 2017). Nevertheless, the use of copper minerals for decorative purposes and their use for copper smelting involve different selection practices and intent, as Radivojević and colleagues have shown in extensive analytical studies across the Neolithic and Chalcolithic Balkan sites in recent years (Radivojević, 2015; Radivojević & Rehren, 2016; Radivojević et al. 2010b). Discriminating between pure green and black-and-green indicated not only aesthetic differences, but also compositional variations, suggesting that copper smiths distinguished between material properties of differently coloured minerals. This is particularly evident in the abundance of manganese oxide in the post-5000 BC Vinča culture copper slags, which is known to facilitate the formation of a melt under variable redox conditions that one would expect from hole-in-the-ground smelting installations (Huebner, 1969: 463; Radivojević & Rehren, 2016, p. 221 ff.). Such a technological practice and clear distinction between minerals for ornaments and those for smelting has not yet been identified in Anatolia or in the Near East. This was the foundation of Radivojević's (2012, 2015) claim that the preference for the black-and-green appearance in the selection of copper minerals by Late Mesolithic/Early Neolithic communities in the Danube Gorges and western Serbia (c. 6200 BC; Fig. 1) prompted early experimentation and subsequent copper smelting between c. 5000 and 4400 BC in the Vinča culture sites of Belovode, Vinča-Belo Brdo, Pločnik and Gornja Tuzla (Fig. 2). This is also the principal new argument underlying renewed claims for an independent technological trajectory for copper metallurgy in the Balkans.

Given the presented evidence, while the practice of sourcing copper minerals and native copper originated outside the Balkans and was brought into the region—presumably accompanying other broadly contemporary materials that were being exploited, such as obsidian—the development of copper metallurgy took a technologically distinctive and independent route in the Balkans from as early as 6200 BC (Radivojević, 2015). The moment of 'invention', though, is difficult to pinpoint but is certainly no later than 5000 BC, when we already see the developed and repetitive process of smelting under similar redox conditions and with similar 'recipes' across the Vinča culture sites (Radivojević & Rehren, 2016). From this perspective, the invention of copper metallurgy could have taken place any time between 6200 and 5000 BC, but most likely during the second half of the 6th millennium BC.

In Eurasia, the closest evidence to the approximately seven-thousand-year-old copper smelting event at Belovode comes from Tal-i Iblis in southeastern Iran in the early centuries of the 5th millennium BC; it is only relatively dated to due to the fact that it comes from excavation of spoil heaps (Frame, 2012). Until very recently, the assumed metallurgical activities at Çatalhöyük had stimulated scholarly debate due to an unusually early date, set at c. 6500 BC, for a find that appeared to display features of a metallurgical 'slag' (Cessford, 2005; Mellaart, 1964; Neuninger et al. 1964). The argument that the Neolithic Çatalhöyük communities were possibly smelting metal has since been discussed in the literature, and been both supported (Hauptmann, 2000; Hauptmann et al. 1993; Strahm, 1984) and called into significant question (Birch et al. 2013; Craddock, 2001; Muhly, 1989; Pernicka, 1990; Radivojević et al. 2010b; Roberts et al. 2009; Tylecote, 1976). A full re-analysis of the original metallurgical 'slag' from Çatalhöyük and revised contextualisation showed that this sample was a burnt copper mineral, probably deposited as a green pigment in a burial and subsequently baked during a destructive fire event in the dwelling in which it was discovered (Radivojević et al. 2017). Further analytical evidence for copper smelting in Anatolia dates from late 5th/early 4th millennium BC occupation of the eastern Anatolian site of Değirmentepe (Lehner & Yener, 2014), although no further analysis of this find is known to the present authors. In summary, the evidence for metal smelting in the Balkans is earlier, more substantial, and technologically distinctive when set against comparable evidence to the east (southwest Asia).

It is important to note that the smelting of copper ores was by no means the earliest application of pyrotechnology in either the Balkans or Anatolia. The transmission of ceramic forms and pyrotechnology from Anatolia to the Balkans occurred from c. 6600 BC, with ceramic production and consumption subsequently being extensively practised and developed by early farming communities (Amicone et al. 2019; de Groot, 2019; Spataro & Furholt, 2020). This process started around 1500 years before the earliest evidence for metallurgy in the Balkans or elsewhere, which leads us to the issue of the interdependence of pottery and metal pyrotechnologies. The most common question about this relationship is whether the ability to create and manage high temperatures (exceeding c. 1000 °C) could have led to discovery of means for the transformation of copper ore to copper metal. Earlier studies of Vinča pottery have already indicated that potters were not achieving temperatures beyond c. 900 °C (1083 °C is the melting temperature for copper) (Kingery &

Frierman, 1974, pp. 204–205). Compositional analysis of the Vinča culture pottery revealed that all fine, medium and coarse fabrics were made of low calcareous clay (less than 6% CaO), and so were normally fired under reducing conditions below 800 °C (Maniatis & Tite, 1981, p. 73).

In new research on the interdependence of pottery and metal technology at the Vinča sites of Belovode and Pločnik within the *Rise of Metallurgy in Eurasia* project, Amicone et al. (2020b) dismiss the importance of high temperatures in pottery firing for proving this relationship. In terms of the mastery of the Vinča potters' pyrotechnological skills, they highlight the more critical skill of controlling firing atmosphere conditions, explaining that the production of a functional pot required temperatures only in the range of 600–700 °C, rather than in excess of 1000 °C; they contend that previous scholarship overestimated the role of firing temperatures in seeking the best fit with the model of interdependence between pottery and metal technologies.

Their findings, however, do not preclude the idea that other advances in pyrotechnology, such as mastery of fire control, could have laid the groundwork for further technological advances such as copper extraction. The only hypothesis from previous scholarship on pottery pyrotechnology that Amicone et al. (2020b) confirmed was that of Frierman (1969), who reports the two-step process for firing graphite-painted pottery, broadly similar to the two-step process of the earliest metal smelting reconstructed by Radivojević and colleagues (2010b, p. 2777). Specifically, experiments showed that graphite burns at 725 °C in an oxidising atmosphere, leading Frierman (1969, p. 43) to assume that pots coated with the graphite slip were fired in an oxidising atmosphere up to c. 500 °C or 600 °C, after which the atmosphere for the remainder of the firing had to be strongly reducing over a prolonged period. The use of a slow firing process under the reducing conditions is further corroborated by the evenness and the black colour of resulting surfaces. The principle of two-step firing also applies to the reduction of copper ores to copper metal, but in reverse order: chemical reduction from ore to metal requires reducing conditions and temperatures from c. 700 °C upwards (Budd, 1991), while the melting of the copper metal takes place under temperatures in excess of 1080 °C, but has fewer constraints on the redox conditions.

Graphite use in the Late Neolithic and Chalcolithic Balkans has been extensively documented (Chokhadzhiev, 2000; Gaul, 1948; Leshtakov, 2005; Todorova, 1986, 1993). While cones of graphite were used to decorate pottery (cf. Gaul, 1948, p. 98), Ryndina and Ravich (2000, pp. 16–17) also speculate on the possibility of graphite-rich moulds being used for metal casting, arguing that craftspeople understood the protective role of graphite against oxidation of freshly cast metal. Although this remains to be confirmed archaeologically, the roughly contemporary emergence of copper smelting and the practice of graphite decoration at the dawn of the 5th millennium BC suggests that they influenced each other. This is particularly true for settlements with strong evidence for metallurgical practice and adjacent graphite deposits, such as Pločnik in south Serbia (Fig. 2), on which Amicone et al. (2020b) build their case. Hence, these technologies are seen as 'close cousins' clearly impacting each other; this highlights the need for future programmes to date the emergence of graphite painted pottery in conjunction with early metallurgy in the Balkans.

The current state of research largely indicates a technology that is unique and has, arguably, an independent route of development in the Balkans, embedded in a long tradition of selecting dark-coloured copper minerals, and potentially also connected to pyrotechnologies that produced dark and shiny materials such as pots—a combination that remains unparalleled in any cultural context anywhere else. Although the authors of this research have had, and continue to have, a divergence of opinions on this particular topic (see opposing views in Radivojević et al. 2010b; Roberts et al. 2009), we agree that the state of early Balkan metallurgy research should inspire similarly detailed studies across Eurasia with respect to the 5th millennium BC, or earlier, as the way to rule among alternative scenarios, as has now been enabled for the claimed, and now rejected, Çatalhöyük metal smelting at c. 6500 BC (Radivojević et al. 2017).

How did Metallurgy in the Balkans Develop?

The development of extractive metallurgy in the Balkans, starting from the time of the earliest evidence of copper smelting at c. 5000 BC and continuing throughout the 5th and into the early 4th millennium BC has been traditionally framed in terms of a regionally coherent technological phenomenon (cf. Chernykh, 1978b; Renfrew, 1969 and literature therein). Furthermore, since the identification of the major early copper mines at Rudna Glava, Serbia (Jovanović, 1978), and Ai Bunar, Bulgaria (Chernykh, 1978a), as well as the discovery of the lavish gold and copper objects in the graves at Varna, Bulgaria (Ivanov, 1978b, 2000), scholarship has focussed on interpreting the metallurgical evidence in terms of major cores and peripheries of metal production and consumption. This approach was refined and elevated by Chernykh (1978b, 1992) with his proposed structure known as the Carpatho-Balkan Metallurgical Province. These two models, of regional coherence and core–periphery structures, can be evaluated against the evidence for: mining and minerals; smelting; making and shaping objects; and copper supply networks.

Mining

Copper mining activities in the Balkans are securely (AMS) dated only at Rudna Glava in eastern Serbia. This mine shows evidence for working from around the mid 6th millennium BC and an intensification of mining activities at around c. 5000 BC (Jovanović, 1971; O'Brien, 2015; Pernicka et al. 1993; Radivojević & Kuzmanović-Cvetković, 2014). At roughly the same time, we see the first copper smelting at the eastern Serbian site of Belovode. Another important and productive copper mine was located in Ai Bunar, central Bulgaria (Fig. 2), which can be relatively dated to c. 4600 BC on the basis of ceramic typo-chronology (Chernykh, 1978a; Pernicka et al. 1997). More recently, Medni Rid in southeast Bulgaria has been confirmed as yet another large copper deposit probably exploited from the mid 5th millennium BC, although this dating is currently based only on provenance analysis and the strong elemental consistency observed between the metal production evidence at Akladi

Cheiri and regional copper metal implements (Kunze & Pernicka, 2020; Rehren et al. 2021).

Rudna Glava is the earliest documented copper mine in the whole of Eurasia. It consisted of eight groups of mine shafts with access platforms, all following veins rich in magnetite, chalcopyrite and carbonate copper ores. Near the entrances and inside the shafts, hoards of distinctive Vinča culture-style ceramics were found, dating from the Gradac phase, broadly between the early and mid 5th millennium BC (the later dates associated with prolonged Gradac phase in the southern Serbian sites), together with stone mallets and deer-antler tools. Despite this extensive evidence for mining, no analyses have yet confirmed that any analysed metal artefact from the Balkans was made from the Rudna Glava copper ores (for an opposing view see Jovanović, 1993; Pernicka et al. 1993, p. 2; Pernicka et al. 1997, p. 143). Intriguingly, trace element analysis of metal production evidence (slag) from the Vinča culture sites of Belovode, Vinča-Belo Brdo and Gornja Tuzla exhibit a very close match with Rudna Glava copper ores; however, both the lead isotope and trace element analysis should be consistent with this metal production evidence. The Rudna Glava lead isotope signature exhibits a wide scatter (due to the radiogenic nature of the deposit), and does not show a close fit to any of the Vinča culture metal implements analysed thus far (Pernicka et al. 1997; Radivojević et al. in press, see also below). Conversely, Majdanpek—one of the most abundant deposits of copper in eastern Serbia and one which has remained viable into the modern period—is only 19 km away from Rudna Glava, and provenance analysis has long indicated Majdanpek copper as one of the main sources for Vinča copper implements (Pernicka et al. 1993, 1997; Radivojević, 2012).

Ancient mining activities are also known from several localities within Serbia, some potentially dating to the 5th millennium BC. These are: Ždrelo in eastern Serbia (near Belovode); Mali Šturac in central Serbia; Medvednik in western Serbia; and Jarmovac in the southwest (Fig. 2) (Antonović, 2014; Jovanović, 1971; Pecikoza, 2011; Radivojević et al. 2010b). In Mali Šturac on Mt. Rudnik in central Serbia, grooved stone mallets resembling those from Rudna Glava were recovered, leading scholars to believe that they were of Vinča-culture provenance (Bogosavljević, 1995; Jovanović, 1983). More recent and ongoing excavations at this site yielded additional material that roughly dates this mine to the mid-to-late 5th millennium BC (Antonović & Vukadinović, 2012; Antonović et al. 2014). Furthermore, grooved stone tools, identical to those discovered at Rudna Glava and Mali Šturac, were found during field surveys of the Vinča culture settlements of Mačina and Merovac (Fig. 2), both situated in the vicinity of the ore-rich deposits at Mt. Kopaonik and Radan in southern Serbia (Kuzmanović-Cvetković, 1998; Radivojević, 1998); these are comparable with stone tools at mining sites throughout Europe (cf. De Pascale, 2003; O'Brien, 2015).

Another potentially Chalcolithic mining site is documented at Jarmovac (southwest Serbia), a complex of ancient mines first mentioned by Davies (1937), who identified Vinča culture sherds in one of the shafts. The site was also excavated by the local museum authorities, who discovered an associated settlement with a late Vinča culture phase (Vinča D) only 300 m away (Bunardžić et al. 2008, p. 86; Derikonjić, 2010). However, subsequent excavations as part of the

Rise of Metallurgy in Eurasia project, in conjunction with the Priboj-on-Lim Homeland Museum and the German Mining Museum in Bochum, recovered an antler pick fragment from a stratified sequence, which was radiocarbon dated to the mid 4th millennium BC (Peter Thomas, pers. comm.). Comparisons to existing trace-element and lead-isotope analyses demonstrate that the mine was most likely in use much earlier to produce metal for copper objects. It is highly likely that further mining sites remain to be discovered along the rich metallogenic belt running through the Balkans (cf. Janković, 1977).

The Mid–Late Chalcolithic (c. 4600–(4450)–4100 BC) was dominated by exploitation of Bulgarian sources, predominantly at Ai Bunar in Bulgaria (Chernykh, 1978b, pp. 54–75). This source, near Stara Zagora in central Bulgaria (Fig. 2), was much larger and had greater production capacity than Rudna Glava, with tunnels up to 500 m long. The material associated with the site belongs to the KGK VI cultural complex, and is therefore relatively dated to the mid–late 5th millennium BC (Chernykh, 1978a, 1978b, 1992). Metal from Ai Bunar is known to have travelled long distances within the Balkans, as far south as Thessaly, and as far north as the northern Black Sea coast (see also below) (Chernykh, 1978b, pp. 122, 263; Gimbutas, 1977, p. 44; Pernicka et al. 1997; Radivojević & Grujić, 2018; Renfrew, 1972, p. 308, fig. 16/2). However, provenance analysis suggested the exploitation of more than one copper deposit in this period, with Medni Rid in southeastern Bulgaria being a very likely candidate (Pernicka et al. 1997, pp. 143–146). The most recent excavations in this location revealed materials from Roman and later times, although some indicate exploitation activities by the communities of the KGK VI cultural complex (Leshtakov, 2013), and this is also supported by recently analysed metal production evidence from Akladi Cheiri (Fig. 3), a settlement nearby. Metal production at this site is argued to date to the late KGK VI, or broadly to the middle of the second half of the 5th millennium BC, based on the typology and ornamentation of pottery found in the same pit as metallurgical evidence (Rehren et al. 2016, p. 207; Rehren et al. 2021). The exploitation of the Medni Rid ores may have started earlier, given the finds of late 6th millennium BC malachite in nearby settlements and the use of malachite for making metal items in the Karbuna hoard, Moldova, which was deposited in a typical Tripolye A pot dating to c. 4700–4600 BC (Fig. 2) (cf. Pernicka et al. 1997; Rehren et al. 2016).

Rather than being mined, starting from around 4650 BC Balkan gold was most likely collected from river streams as alluvial (washed) nuggets that had eroded from primary deposits (Avramova, 2002; Boyadžiev, 2002; Makkay, 1995, p. 70). This suggestion has been elaborated recently in a study of Varna gold, where Leusch et al. (2014) presented a diversity of gold, copper and silver ratios in the excavated gold artefacts, explaining that they originated from natural compositional variations in (alluvial) gold nuggets. This in turn demonstrates that various gold occurrences were exploited for the making of Varna gold, and possibly acquired through a well-organised gold supply network (Leusch et al. 2015). Such supply networks also could have supplied the copper, Spondylus, carnelian, marble, serpentinite, long yellow flint blades (*superblades*) and other prestige commodities unearthed as paraphernalia in the Varna cemetery (Leusch et al. 2017).

Smelting

Smelting evidence from the Early Chalcolithic is extremely scarce and mostly limited to the Vinča culture phenomenon in the central Balkans (Table 1; Fig. 4b–f). Even before the appearance of analytically extensive studies of the early metal production debris from a selected number of Vinča culture sites (Glumac, 1991; Radivojević, 2007, 2012), there had been hints that smelting was taking place. For example, in 1976 Marija Gimbutas had mentioned a copper slag lump from the site of the Anzabegovo settlement in the eastern part of Northern Macedonia (Gimbutas, 1976). Anzabegovo generally dates to c. 5200 BC, but the find itself has never been chronologically or analytically verified. Moreover, in its relative regional vicinity, in the valley of the Strymon River at the Greek–Bulgarian border, is the site of Promachon-Topolnica, which has yielded indicative field structures ('hollows' with traces of copper), of which the most important is a small clay crucible with a spout, dated broadly to the first half of the 5th millennium BC (Koukouli-Chryssanthaki et al. 2007, p. 51; Fig. 7.4). While the authors reported that the crucible contained traces of non-slagging copper processing with distinct traces of heavy burning, no analyses are available, which makes a more accurate identification challenging. A similarly vague situation pertains at the site of Stapari, where an alleged lump of slag was dated relatively to within the late Vinča culture phase (Jurišić, 1959). Pieces of 'greenish slag resulting from intense fire' were reported at depths of below 6.2 m, below 6.4 m, and below 7.0 m at Vinča-Belo Brdo (Vasić excavations), however, no further analysis or details of these finds are available (Antonović, 2002, p. 36, note 59).

Microstructural, chemical and isotopic analysis of copper slag and other production evidence from the sites of Belovode, Vinča-Belo Brdo (Tasić excavations), Pločnik, Gornja Tuzla and Selevac are the first secure evidence for sustained metallurgical activities within the Vinča culture, and highlight its role as the core archaeological phenomenon in the evolution of Balkan metallurgy (cf. Čović, 1961; Glumac & Todd, 1991; Govedarica, 2016; Radivojević, 2012; Radivojević & Rehren, 2016).

The approximate chronological sequence for the finds studied by Radivojević (2015) starts with the Belovode slags at c. 5000 BC, a date confirmed by further slags and copper metal debris excavated, analysed and directly dated in new excavations to c. 4900 BC (Radivojević et al. in press). It continues until c. 4600 BC, with an overlap of around 200 years with the Vinča-Belo Brdo production evidence, itself dated in the range c. 4800–4600 BC. Copper smelting continued at the settlement of Gornja Tuzla for as long as two hundred years following the abandonment of Belovode and Vinča, that is, down to c. 4400 BC. Both macro- and micro-analytical approaches demonstrate that copper smelting was, in total, practised throughout a period of about six hundred years, with remarkable similarities in the level of expertise and the technological choices made, although with clear differences in the composition of the ores smelted. The striking detail that underlines the chemistry of ores smelted at the sites of Belovode, Vinča, and Gornja Tuzla is their dominant colour: whatever were the exact minerals present in the ore charge, they most likely had strong colours in the range of green/blue (vivianite, arthurite, apatite, scorodite), and violet (strengite), in addition to black-and-green, manganese-rich malachite (Belovode and Vinča only). Such a conclusion has been corroborated by a detailed inspection of the slag matrix and the residual ores found in it. It is also important to underline that the indicated ores were not necessarily especially rich in copper; rather, it was their striking green/blue/violet colours that seem to have attracted the Vinča prospectors (Radivojević & Rehren, 2016, p. 225 ff.). Although it is not clear from the analyses whether black-and-green minerals were selected separately or as a mixed ore, the conclusion that emerges from the analytical discussion is that there was common knowledge of the suitability for smelting of distinctively coloured mixed minerals at this time at these various sites.

The Vinča-culture metal production practice fits well within the 'ephemeral model' of Chalcolithic metallurgy in western Eurasia (Bourgarit, 2007); the individual slags weigh a little less than 10 g in total (see example in Fig. 4b). This is commonly explained by the use of much cleaner ore in the early stages, resulting in a 'slagless' or nearly slagless metallurgy (cf. Craddock, 1995). Depending on the relative proportions of (slag-forming) dark components in the ore and pure green mineral, a large amount of copper may have formed with only a small quantity of slag, and this is the favoured scenario in the recent analytical studies (Radivojević & Rehren, 2016, p. 227 ff). Noteworthy, though, is the discovery of a lead-based slag cake weighing nearly 800 g in an undisturbed horizon dated to 5200 BC in Belovode. As this is a unique find currently unsupported by wider evidence indicating established lead metal production, it will be addressed in detail in the 'lead and silver' section below.

The structures in which smelting took place—so-called smelting 'furnaces', are evidenced primarily by slagged sherds at both Belovode and Gornja Tuzla (example in Fig. 4c–d). These suggest the presence of a hole-in-the-ground installation lined with broken pottery. Such installations were possibly operated using blowpipes/tuyères or bellows, where five or six blowpipes would normally suffice to bring the temperature up to around 1100–1200 °C (cf. Rehder, 1994, p. 221). The only indication of what these blowpipes may have looked like is found in the ceramic nozzles recovered from the sites of Bubanj (Fig. 4e–f) and Kmpije in Bor. In the absence of any other evidence, the hole-in-the-ground installations appear to be the only technological possibility for primary metal production in the early-to-mid 5th millennium BC (see Fig. 4c, d). In addition, although no crucibles have yet been properly analytically identified in the record, their presence must be assumed, given that they would have been needed for (re)melting and casting of the thousands of heavy metal objects known from this period. It may be legitimate to identify two vessels from the site of Reșca–Dâmbul Morii in Wallachia, Romania, as crucibles. These are oval, ladle-like vessels with a short, vertically pierced handle, displaying secondary traces of firing (Fig. 2; Stefan, 2018, p. 119, table VII/1, 2). These have not yet been analysed, and their context is still under discussion, although they are argued to belong to the Vădastra culture horizon, which dates to between 5200 and 5000 BC; nevertheless, they may well be the best clue concerning the appearance of crucibles during this period. Curiously, the casting moulds that were unequivocally necessary for producing the vast number of metal implements produced in this period are also absent from the archaeological record (Heeb, 2014; Kienlin, 2010, p. 42 ff).

Copper production evidence is still scarce in the Mid–Late Chalcolithic (c. 4600–4100 BC), although it is documented in more settlements than for the previous period. In Bulgaria, copper smelting evidence comes from the sites of Dolnoslav, Chatalka and Akladi Cheiri (Fig. 3), all dated to the mid-to-late 5th millennium BC (Rehren et al. 2016, 2021; Ryndina et al. 1999). All three sites yielded crucibles, amongst other finds, although only the Dolnoslav and Akladi Cheiri examples were preserved. The crucible from Dolnoslav was a vessel with an oval plan, round bottom and 10–25 mm thick walls (Ryndina et al. 1999); the reconstructed example from Akladi Cheiri had a similar oval base though the frontal part was slightly profiled to serve as a spout (Rehren et al. 2016, p. 207; Fig. 2). Microstructural and compositional analyses of the Dolnoslav crucible indicated smelting of polymetallic ores (a mix of malachite with primary copper ores), which were rich in zinc and lead oxide (Ryndina et al. 1999, p. 1066, table 2). The dominant presence of zinc and lead in the slag matrix, together with copper oxide in trace amounts, presents a copper smelting technology that is different from, and possibly more efficient than, that encountered in the Vinča culture with its slags rich in manganese oxide (Radivojević, 2015, p. 332, table 2). The Akladi Cheiri example on the other hand was for (re)melting: its inside was contaminated with copper and there was no other evidence for gangue elements such as iron, cobalt or sulfur (Rehren et al. 2021: p. 152). These are the earliest definitively identified crucibles in the Balkans, and they become more common only from the mid 4th millennium BC, notably in the Baden culture in the north-central Balkans (Ecsedy, 1990, p. 224; Glumac & Todd, 1991; Radivojević et al. 2010a).

More examples, although not analytically confirmed, come from the late 5th millennium BC Tiszapolgár culture cemetery of Tibava (Fig. 3), in the form of a cylinder vessel with a crude inner surface, identified amongst pottery grave goods (Andel, 1958, Plate I/7; Šiška, 1964, p. 317; Fig. 12/5); this was thought to be a melting pot but it was never analysed (Bognár-Kutzián, 1972, p. 134). Another crucible described as a ‘vessel covered with blue verdigris and with two small copper crumbs’ was discovered among grave goods in the cemetery of Tiszapolgár-Hajdúnánás Road, and has unfortunately been lost (Bognár-Kutzián, 1972, pp. 98, 134). The ceramic vessels widely interpreted as crucibles at the Cucuteni A2 and B1 levels at the site of Poduri-Dealul Ghindaru in Romania (Fig. 3; Mareş, 2002, pp. 85, 138–139, table 64/8) have yet to be subjected to archaeometallurgical analyses and so cannot be considered as confirmed metal production evidence, despite the presence of two copper ingots from the same site (Monah et al. 2002). A similar situation is encountered in Sitagroi (phase III, roughly contemporary with KGK VI), where an assemblage of 36 slagged sherds, accompanied by copper metal artefacts, present convincing evidence for local copper smelting as well as a distinctively similar slagging pattern to contemporaneous Akladi Cheiri, for instance (Renfrew & Elster, 2003, pp. 306). These sherds are yet to be subjected to detailed technological analysis.

The hole-in-the-ground smelting installations identified earlier in the Vinča culture sites find parallels at the site of Akladi Cheiri, near Sozopol in Bulgaria (Fig. 3). Here, an exceptional discovery of 300 ceramic sherds with traces of firing and slag adhering to them testifies to intensive metal production activities in the foothills of the Medni Rid (that is, close to known copper deposits). This evidence dates to later phases of the KGK VI complex of the late 5th millennium BC (Rehren et al. 2016) and consists of a metallurgical workshop containing fragmented slagged sherds that possibly lined a hole in the ground; these are associated with slags and the melting crucible mentioned above, which is similar to those hypothesised at the Vinča culture sites of Belovode and Gornja Tuzla (Radivojević & Rehren, 2016). Analysis of slag from Akladi Cheiri revealed features already observed for early copper smelting elsewhere, such as high degree of variability in the slag matrix, ranging from glassy to micro-crystalline with the formation of inclusions. Redox conditions were equally varied. The presence of fayalite, clusters of magnetite with matte and copper metal, copper sulphides, olivine crystals, delafossite and cuprite across the studied assemblage speaks of unstable firing conditions during the smelt and different levels of exposure of the slagged sherds during the smelting events (Rehren et al. 2021), all of which are known features of the earlier examples from the Vinča culture. More slagged sherds from the mid-to-late 5th millennium BC come from the site of Kmpije in Bor in eastern Serbia (Fig. 3), where a slagged sherd was discovered in association with copper metal artefacts. Analytical work is underway in collaboration with one of the authors (MR) and I. Jovanović from the Mining Museum in Bor.

Interestingly, a piece of slag was deposited as a grave offering (?) in the late 5th millennium BC Lengyel culture cemetery of Zengővárkony, Hungary (Fig. 3). It was found, together with numerous ceramic vessels, in the well-contextualised grave of a middle-aged woman with two pure copper spiral bracelets on each arm (Dombay, 1939; Glumac & Todd, 1991, p. 14). Slag analyses revealed mineral phases of cuprite and cassiterite, copper metal prills with a significant content of tin, ranging from 0.4 to 37 wt%, as well as relevant concentrations of tin in slag silicates (Glumac & Todd, 1991, p. 14). Ottaway and Roberts (2008, p. 197) discuss this find as accidental co-smelting of copper and tin-bearing ores since, compositionally, it pre-dates tin alloys in the region. The recently discovered piece of tin bronze foil, dated to c. 4650 BC (Radivojević et al. 2013a, b), at the site of Pločnik in south Serbia suggests, however, the potential intentionality of the Zengővárkony copper-tin slag. In terms of cultural significance, Glumac and Todd (1991, p. 15) argue that the copper smelting might have played a ritual role for the community buried at Zengővárkony, while Taylor (1999, p. 29) interprets it as a symbolic 'afterbirth' and hence more a matter of gender than offering. This view is supported by the discovery of more copper smelting debris in the early 4th millennium BC Lengyel-culture burial site of Brzec Kujawski, central Poland.

Making and Shaping Metal Objects

While the mining and smelting evidence across the Balkans from the approximate period 5000–3700 BC is fragmentary and copper-oriented, recent research has produced a far greater quantity and quality of data relating to the creation of different metals by smelting, melting and alloying, and to the creation of different forms in those metals by casting, annealing and cold/hot working. The regional coherence and core–periphery models are evaluated here against each metal and its associated object production technologies.

Copper

Copper metal jewellery and small tools appear alongside malachite beads and pendants in the early 5th millennium BC in the Balkans. They are usually found in settlements and cemeteries located in the lower Danube basin and further towards the northern Black Sea coast, such as Gomolava (Brukner, 1977), Gornea (Lazarovici, 1970, p. 477), Cernavodă (Berciu, 1967, p. 53) and Izvoare I in Romania (Vulpe, 1957, figs. 72/3, 85/5,6), or Lukavrublevetskaya on the Dniester (cf. Bibikov, 1953; Bognár-Kutzián, 1976, p. 71; Figs. 1, 2).A copper metal bead from the site of Dikili Tash I in northern Thessaly is speculated to be made of either native or smelted copper (Séfériadès, 1992, p. 114). Noteworthy is the unique context of Gomolava metal found with some of the deceased in this male-only cemetery dated to 4700–4650 BC, including copper beads buried with an infant. Ancient DNA analysis has shown that the individuals in the cemetery are of the same lineage, prompting assumptions of copper metal related to an inherited status in the case of the infant (Brukner, 1980; Stefanović, 2008).

The earliest *smelted* copper metal implements originate from the sites of Pločnik in south Serbia, Slatino in western Bulgaria, Devebargan-Maritsa in northern Thrace and Durankulak on the Black Sea coast (Fig. 2) (Pernicka et al. 1997, pp. 48, 72, 131, Table A1; Radivojević, 2012); of these, only Durankulak is a cemetery, while the others are settlements. The difference between the artefacts made from native copper or smelted copper ores lies in the trace element analyses; while objects made of the latter contain relevant readings of cobalt and nickel as discussed above, the concentrations of these elements in the former are close to non-detectable (Pernicka, 1990; Pernicka et al. 1997). In burials, copper implements were usually accompanied by *Spondylus* and *Dentalium* beads, or bone, clay or marble figurines, as in the Devnja (Devnya) cemetery on the Bulgarian Black Sea coast (Todorova-Simeonova, 1971, pp. 23–25). One of the most impressive collections of massive copper implements comes from Pločnik, where 38 copper metal artefacts were discovered (Antonović, 2014; Grbić, 1929; Radivojević & Kuzmanović-Cvetković, 2014; Šljivar et al. 2006; Stalio, 1964). These include: four hammer-axes of Pločnik type, 25 chisels, a copper ingot bar and a pin, altogether weighing c. 16 kg. They are a unique assemblage of early copper metal and, based on the most recent AMS dating of a fragmented copper chisel to c. 5040–4840 BC found separately during modern excavations (Radivojević & Kuzmanović-Cvetković, 2014, p. 23; Whittle et al. 2016), they are one of the earliest in this part of Eurasia. Seventeen copper metal tools from Pločnik were studied for their chemical composition and lead isotopes (Pernicka et al. 1993), revealing an unexpected complexity of ore/metal exchange networks. At least three different copper deposits from eastern Serbia, Macedonia and across Bulgaria provided metal for their production. The only closely comparable collection is that from the Rakilovci hoard in western Bulgaria, where a total of nine copper metal implements were recovered from a ceramic pot (Mihaylov, 2008).

A further exceptional copper metal assemblage comes from the site of Karbuna in Moldova: of the 852 precious objects discovered as a hoard in a typical Tripolye A pot (c. 4700–4600 BC), 444 were made of pure copper (Dergachev, 2004; Sergeev, 1963, p. 135; Videiko, 2004). Significantly, the hoard included two massive copper implements, one being a hammer-axe of Pločnik type (broadly dated to the early-to-mid 5th millennium BC) (see also Diaconescu, 2014). The considerable volume of the find and distinctive typology of its contents suggest close associations with contemporary cultures in both Serbia and Bulgaria (Chernykh, 1991, pp. 581, 587). Chernykh (1966, pp. 53–58, 86–88; 1978b, p. 122; 1991, pp. 387, 581) argued that the Karbuna hoard metal could have come from Ai Bunar, while Pernicka speculated that it might have derived from Medni Rid in eastern Bulgaria, since artefacts from north-eastern Bulgaria, southeastern Romania and further to the northeast fit well with the compositional pattern of Medni Rid (Pernicka et al. 1997, pp. 141). Interestingly, based on its distinctive chemical signature, this metal was probably recycled and traded further north towards the Volga valley and into the steppes (Chernykh, 1991, p. 587–588; Fig. 5).

Further to the northwest, the early appearance of copper artefacts is more modest and accumulated mostly in the Great Hungarian Plain and Transdanubia, or the Tisza–Hérpály–Csöszhalom group, Železiowce and Lengyel cultures (Ecsedy, 1990, p. 220). Copper jewellery, awls and chisels come from the sites of Mlynárce (Novotný, 1958, p. 28), Neszmély, Csöszhalom, and Hódmezővásárhely-Kopáncs-Kökénydomb (Bognár-Kutzián, 1963, pp. 331–333), all located along or near the major rivers in this area. Metal artefacts are also recorded at sites located along the Tisza River and closer to the Carpathian Mountains, such as the settlements of Hérpály, Berettyószentmárton and Zsáka-Markó, as well as the Gorsza cemetery (Bognár-Kutzián, 1963, pp. 331–336, 487).

In contrast to the central Balkans after the collapse of the Vinča culture, the production of massive copper metal implements flourished in eastern Bulgaria during

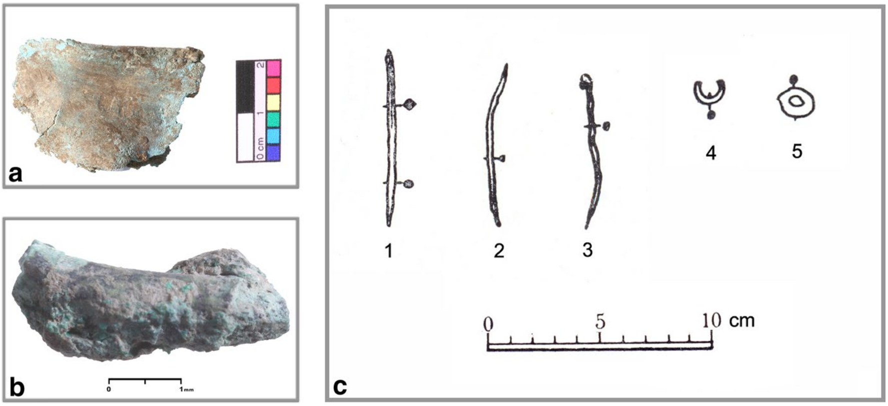

Fig. 5 A selection of the 5th millennium BC tin bronze artefacts from the Balkans. **a** Pločnik foil; **b** Gomolava ring; **c** 1. Bereketska Mogila, 2. Gradeshnica, 3, 5. Ruse, 4. Karanovo (adapted after Chernykh, 1978a, b, tables 15/24,42; 18/30; 19/4,7; Radivojević et al. 2013a, b)

the second half of the 5th millennium BC. This can be followed archaeologically from the mid 5th millennium BC Hamangia IV phase (Table 1) (Boyadžiev, 2002, p. 67), when mass metal consumption is reflected by the exceptionally rich grave goods recovered from burials in Varna and Durankulak, including both copper and gold objects (Ivanov & Avramova, 2000; Ivanov, 1978a, 1978b, 1988a, 1988b; Todorova, 2002). Massive copper implements and gold decorations were also found in settlements, for example in Hotnica, Ruse, Kasla-Dere, Gumelniţa or Vidra, all set along or in the hinterlands of the lower Danube (Bognár-Kutzián, 1976, p. 71; Gimbutas, 1977, p. 44).

Comprehensive typological schemata have been developed to track the appearance of specific types of massive copper implements. Changes in the morphology of hammer-axes are particularly interesting as they appear to be related to specific regions across the Balkans. For instance, hammer-axes of the Pločnik type are generally associated with the Vinča culture (these start to appear in the Early Chalcolithic), the Vidra type with the north-central Bulgarian sites (associated with the KGK VI), while the Čoka-Varna type is characteristic of the north-eastern Bulgarian sites (Varna culture) (Antonović, 2014; Chernykh, 1978b; Govedarica, 2001; Kuna, 1981; Novotna, 1970; Radivojević, 2006; Schubert, 1965; Todorova, 1981; Vulpe, 1975; Žeravica, 1993). Importantly, lead isotope analyses of the late 5th millennium BC Vidra and Čoka-Varna hammer-axes showed that they were made of the same metal (Pernicka et al. 1997, pp. 94–98, 105–106, 142, table 3), indicating that there was no relationship between a metal source and a tool type. The strong preference for a specific tool type regardless of source potentially suggests that particular technological choices reflect the identity of a producer or consumer group.

Scholarly debates regarding the Final Chalcolithic period in the Balkans (c. 4100–3700 BC) have traditionally been dominated by narratives of a societal collapse in eastern and central Bulgaria, as indicated by a substantial reduction in archaeologically visible (and dated) settlements (Kienlin, 2010; Weninger et al. 2009). Metal provenance data also support this interpretation with a noticeable shift in copper supply networks from the eastern to the central Balkans, which witness an intensification with the exploitation of novel sources in the Carpathian Basin (Pernicka et al. 1997; Schalk, 1998; Siklósi & Szilágyi, 2019; Siklósi et al. 2015) (see also next section). The presence of increasing numbers of copper objects in the northern Alpine region (cf. Bartelheim, 2007; Cevey et al. 2006; Kienlin, 2010, 2014; Klassen, 2000; Scharl, 2016; Turck, 2010), as well as throughout the neighbouring central Mediterranean region (Dolfini, 2013, 2014), provides evidence for the emergence of other copper industries outside the 'core' Balkan region, although these are still considered to be associated with the Balkan sources (Höppner et al. 2005).

Copper production rapidly changes in the late 5th to early 4th millennium BC with metal production re-emerging in the central and northwestern Balkans, as shown by the increase of metal consumption in the Bodrogkeresztúr culture and the intensified exploitation of eastern Serbian and western Bulgarian copper sources (Pernicka et al. 1997, pp. 98–101, 105–106, table 3). As a consequence, the earliest metal-using cultures, including Mondsee and Pfyn, emerge north of the Alps (Kienlin, 2010; Krause, 2003; Ottaway, 1989); however, in contrast to the quantity of copper implements recorded, production evidence is extremely scarce and understudied. Cultures of the late 5th millennium BC Great Hungarian Plain produced the first known metal knives, and massive copper implements are found in both settlements (e.g. Lucska) and cemeteries (e.g. Tibava) (Bognár-Kutzián, 1972, p. 140; Hansen, 2013b; Šiška, 1964, p. 7 ff.; Todorova, 1995, p. 90). One of the most exceptional collections of metal artefacts in this region comes from the late 5th millennium BC Lengyel culture cemetery of Zengővárkony (Fig. 3), where a large number of spiral copper metal bracelets, rings and malachite beads were deposited as grave goods (Dombay, 1939, pp. 50–64; 1960, pp. 75–144; Ecsedy, 1990, pp. 212–218). Noteworthy are the cemeteries, like Rákóczifalva-Bagi-föld, where the uneven distribution of grave goods, including copper and gold objects, potentially indicates a degree of social inequality (Csányi et al. 2009), as evaluated across the Eastern Carpathian Basin by Siklósi (2013).

Tin Bronze

The recent excavation and archaeometallurgical analysis of a tin bronze foil at Pločnik from a secure context radiocarbon dated to c. 4650 BC (Radivojević et al. 2013a, b) has revealed the emergence of tin bronze metallurgy at this time. The compositional analyses of the Pločnik tin bronze foil indicated that stannite (Cu_2FeSnS_4), a copper-tin-bearing mineral, was the probable ore used for making this natural alloy with c. 12wt% Sn and relevant traces of As, Fe, Co and Ni in a smelt that contained both stannite and malachite (see Radivojević et al. 2013a, b, p. 1035, Table 1). This means that the earliest known tin bronze artefact was not made by alloying two elements (copper and tin) but rather by smelting a copper-tin-bearing ore.

There are 14 additional tin bronze artefacts known from the mid–late 5th millennium BC, however—based on geochemistry that links them with the Pločnik foil—these finds only occurred together in what appears to be a short-lived tin bronze horizon in the Balkans. Twelve finds originate from the Bulgarian sites of Ruse, Karanovo, Gradeshnitsa, Smjadovo, Zaminec and Bereketska Mogila (Chernykh, 1978b; Pernicka et al. 1997), and two from the Serbian sites of Gomolava and Lazareva Cave (Glumac & Todd, 1991, p. 15; Ottaway, 1979; Tasić, 1982). The assemblage of awls, rings, needles, borers and a rod from Bulgaria and Serbia (Fig. 5) has tin concentrations ranging from 1 to 10wt%, with consistently significant levels of lead, arsenic, nickel, cobalt, iron and gold (Chernykh, 1978b, pp. 112, 339, 342–343, 351–352, tables 15/24,42; 18/30; 19/4,7; Pernicka et al. 1993, p. 190, table 3; Pernicka et al. 1997, pp. 70, 121–126, 156, table A1).

In terms of context, 13 of the 14 finds are to some extent stratigraphically insecure, the exception being a borer from Ruse originating from the secure, primary context of a child's burial (Glumac & Todd, 1991, p. 15; Pernicka et al. 1997, pp. 125–126). Despite having different chemical compositions, these tin bronze objects typologically match contemporary regional counterparts in pure copper, yet overall their form is culturally non-diagnostic and chronologically imprecise, offering little information about exact provenance. The Pločnik tin bronze foil has therefore been crucial in determining their chronology by revealing a unique, shared chemical signature (Radivojević et al. 2013a, b). The attribution to the mid–late 5th millennium BC is made more plausible by the fact that no other tin bronze artefacts are known in the Balkans before the 3rd millennium BC at the earliest, and the material only becomes widespread in the 2nd millennium BC (Chernykh, 1978b; Pare, 2000; Pernicka et al. 1997; Schickler, 1981). This suggests that these finds are most unlikely to be intrusions from any later layers on the sites where they have been documented.

Another artefact with relevant tin content (c. 1.5wt%) and minute concentrations of silver and nickel in the copper base, originates from a mid-to-late 5th millennium BC phase at Dikili Tash II in Greek Eastern Macedonia (Fig. 3) (Sériadès, 1992, pp. 114–115, table 12). The trace element signature of this object is not, however, consistent with the tin bronze assemblage from Bulgaria and Serbia, although it was probably also made by co-smelting malachite and tin-rich ore. A tin-rich slag piece from the late 5th millennium BC cemetery of Zengővárkony, the only technological debris of its kind at the time, adds more chronological certainty for the production of tin bronzes mentioned above. Yet, the context of this particular artefact remains uncertain (Pernicka et al. 1997, p. 125).

Radivojević and colleagues (2013, p. 1040) further argued that the golden hue of these 15 documented Serbian and Bulgarian tin bronze artefacts, which contain between c. 1wt% Sn to c. 12wt% Sn, must have been critical to their value in the 5th millennium BC, particularly as these artefacts were roughly contemporary with the emergence of the earliest known gold artefacts, unearthed in the cemeteries of Varna and Durankulak in Bulgaria (cf. Avramova, 2002; Dimitrov, 2002; Higham et al. 2007, 2018; Ivanov, 1988b; Krauss et al. 2017; Leusch et al. 2014; Todorova & Vajsov, 2001). The importance of the new colour palette at the time has been emphasised in detailed compositional analyses by Leusch et al. (2014), which showed that not all gold items in the Varna cemetery had the same shade of yellow. We may assume that the rarity of objects coloured in these new shades in the 5th millennium BC Balkans might have dictated their limited production, but also that demand for them was both social and technological: such tin bronzes disappear with the collapse of the KGK VI (and related cultural phenomena) at the end of the 5th millennium BC in the Balkans. In contrast to the tin bronzes, there is currently no evidence for arsenical copper objects and their production in the Balkans prior to the early-to-mid 4th millennium BC (e.g. Antonović, 2014; Chernykh, 1978b; McGeehan-Liritzis & Gale, 1988; Nerantzis et al. 2016; Pernicka et al. 1997).

In order to investigate the golden hue argument in greater detail, Radivojević et al. (2018) designed a Cu–As–Sn colour ternary diagram based on an extensive set of experiments that yielded 64 binary and ternary metal pellets which could then be subjected to colorimetric analysis. The values for the 15 Balkan tin bronzes were then plotted on this colour diagram in three distinctive groups, based on the probable mixture of ores (other than malachite) in the smelting charge: stannite, high-tin fahlore and low-tin fahlore (data from Radivojević et al. 2013a, b, p. 1035, Table 1). Figure 6 indicates that the stannite and high-tin fahlore group (12 artefacts, Sn range between 6wt% and 12wt%) had a visibly emphasised golden hue when produced, as opposed to the low-tin fahlore group where, although colour change would have been noticeable, it was not as significant as for those above c. 5wt% (Radivojević et al. 2018, pp. 115–118; Fig. 12).

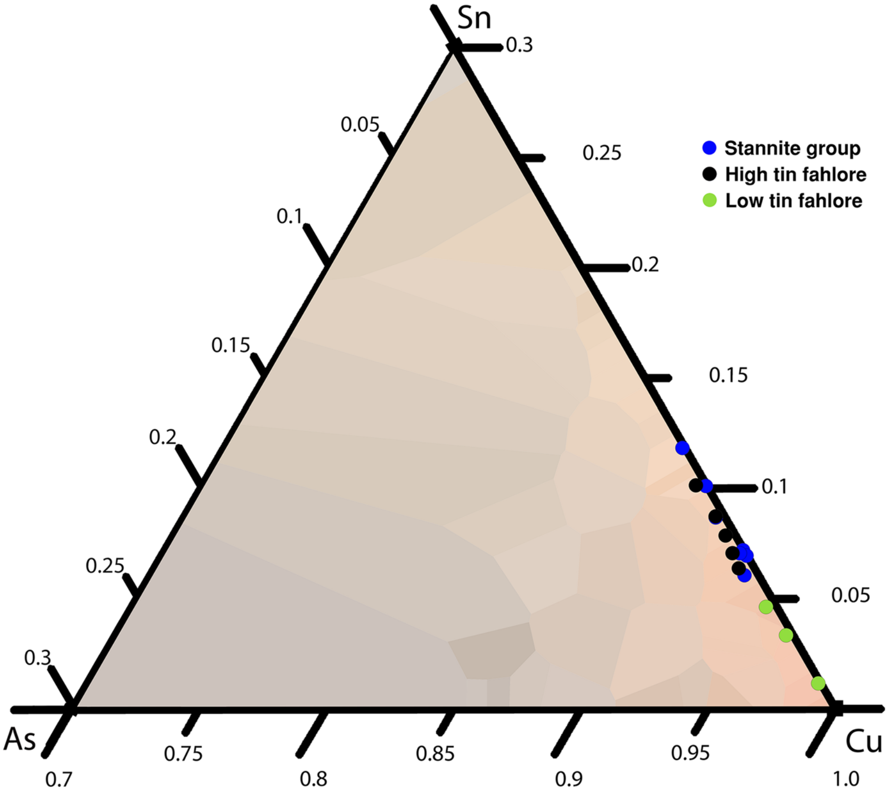

Fig. 6 The mid to late 5th millennium BC Balkan bronzes plotted against the Cu–As–Sn ternary colour diagram (100wt% Cu-30wt% As-30wt% Sn corner, see Fig. 8). Fifteen artefacts split into three groups indicate a variety of colour changes, significantly visible after c. 5wt% Sn on the Cu-Sn axis. Data from Radivojević et al. (2013a, b, p. 1035, Table 1); image from Radivojević et al. (2018a, p. 118, fig. 12). (Color figure online)

It was therefore concluded that the group of 5th millennium BC Balkan tin bronze artefacts, in particular the assemblage of stannite and high-tin fahlore group, must have appeared significantly different, aesthetically, from pure copper artefacts, since the addition of tin increased their golden hue. With such a different appearance, it is very likely that the production of the 5th millennium BC Balkan tin bronzes was dictated by the demand for the 'exotic' golden colour at the time, or by the pursuit of its closest imitation, which supports the claims in the original publication (see also Radivojević et al. 2013a, 2014a). It is also very interesting that the shape of the Pločnik foil (Fig. 5a) indicates that it was wrapped around an object, which could have been a pottery vessel or a stone, wood, bone or copper object. If we seek inspiration for the use of foils at that time (c. 4650 BC), metal foils with the same golden colour (see Fig. 6) are found in abundance in the Varna burials. The most notable examples come from the rich burials 36 and 43, including the infamous golden 'penis sheath' (Leusch et al. 2017).

Ryndina and Ravich (2001, p. 4; Fig. 3) maintain that the provenance of the Balkan early tin bronze artefacts may have been associated with local sources, since their chemical signatures correlate well with those of copper metal that circulated in Transylvania, Hungary and northern Yugoslavia, extending towards Moldavia and Ukraine. Conversely, Pernicka et al. (1997, p. 141) argue that the tin bronze artefacts he analysed did not fall within the isotopic range of the majority of artefacts from the 5th millennium BC. In her doctoral thesis, Radivojević (2012) showed that the provenance of Pločnik tin bronze foil was highly consistent with the rest of the Pločnik copper implements.

While the provenance of these artefacts remains to be explored in future publications, it is important to emphasise that the information we have assembled thus far speaks in favour of the limited use of tin bronzes across the Balkans in the late 5th millennium BC. Furthermore, it is essential to remember that although the excavation methodology used in their discovery varied, the excavators were not aware of the relevance of tin bronze objects based on their appearance (the green patina appears similar to that found on pure copper objects), and hence they could not have been biased in their recording. If anything, these items were mislabelled as ‘ordinary copper’ until chemical analysis showed otherwise (as was initially the case with the Pločnik tin bronze foil).

Although this early use of copper-tin ores to make natural alloys has only started to emerge in the literature, special caution is needed regarding claims that involve superficial or rapid analyses and insufficiently elaborated contextual evidence. This applies to the as yet unchallenged assertions about the 6th millennium BC emergence of naturally alloyed tin bronze artefacts from the sites of Tel Tsaf in the Southern Levant (Garfinkel et al. 2014) and Aruchlo in Georgia (Hansen et al. 2012) which, in the light of this discussion, deserve attention here. The Tel Tsaf metal awl was discovered in a secondary context (burial in a silo) in what is currently claimed to be a largely Middle Chalcolithic horizon, broadly dated to between 5100 and 4600 BC. The authors ascribed the metal awl to the late 6th millennium BC (Garfinkel et al. 2014), even though the skeletal burial had enough datable materials (i.e. bones) available to obtain a secure date. Furthermore, even if the secondary context is truly Middle Chalcolithic, its characteristics are more indicative of the end of the silo use-life, which should therefore be around or sometime after 4600 BC. The analysis of this heavily corroded awl ‘with no original metal left’ (Garfinkel et al. 2014, p. 3), conducted with portable ED-XRF, implied an Sn content between 3.5 and 7wt%. While the authors of this study acknowledge that these figures may be overestimated given that tin is known to be relatively immobile in most burial conditions compared to copper and hence usually found enriched in corroded layers, the questions remain: how much tin was there, and was it enough for its crafters to detect any difference in the performance of the artefact, or its colour?

Comparative analysis of tin bronze artefacts using handheld XRF and EPMA (Electron Probe Micro Analyser) indicate that the former technique can differ around 20% from the true metal body values when applied to the metal surface cleaned from corrosion, or c. 70% or more when performed on the corroded surface of the same object (Orfanou & Rehren, 2015). Although we do not know exactly the effect of the burial deposits on the enrichment of tin in the Tel Tsaf artefacts, estimates based on the reported XRF analysis in Garfinkel et al. (2014, p. 4, Table 1) indicate that the true value of tin content in the Tel Tsaf awl could potentially be as low as c.1wt% and 2wt%. While this is a speculative calculation with many unknowns, with such a composition the Tel Tsaf awl would still qualify as a tin bronze but without any indication of intentional alloying, which is a key factor for the tin bronze foil from Pločnik in Serbia. The colour range of the awl would in this case barely differ from that of common contemporary copper artefacts, even with up to c. 5wt% of Sn content (see Fig. 6), which suggests that the process of its making, if truly contextualised towards the end of the Middle Chalcolithic, probably made no difference to its appearance at the time. The Aruchlo bead from the Neolithic site in Georgia is also optimistically set at the early end of its date range, at 5800–5300 BC, while the handheld XRF analysis of this heavily corroded item (again with no metal body preserved) reveals a compositional structure of what looks like predominantly malachite mineral with relevant impurities of tin, arsenic and iron, which are comparable with the polymetallic mineralisations in that area (Bastert-Lamprichs et al. 2012; Hansen et al. 2012). In sum, the claims for the emergence of early tin bronzes in the Levant and Georgia in the 6th millennium BC require more rigorous analytical probing in order to substantiate their published interpretations.

Gold

The appearance of thousands of small decorative objects made of gold dates from the mid 5th millennium BC in north-eastern Bulgaria, southeastern Romania and northern Thessaly (Higham et al. 2007; Krauss et al. 2017; Makkay, 1991). Although the gold from the cemetery of Varna I is claimed as the earliest known (dated most recently between 4690 and 4330 cal BC) (Krauss et al. 2016), there are earlier uses of gold ornaments (although not as securely dated) in the Varna II cemetery (Todorova & Vajsov, 2001, p. 54), as well as in the cemetery of Durankulak (Avramova, 2002, pp. 193, 202, table 24; Dimitrov, 2002, p. 147). The Durankulak finds are, for instance, dated to the Hamangia IV phase, c. 4650/4600–4550/4500 BC (Bojadžiev, 2002, p. 67). Gold also appears in more modest quantities in sites located in the lower Danube basin—as at Vidra (Dumitrescu, 1961, p. 80), Hotnica (Jovanović, 1971, p. 37), Traian, and Gumelniţa (Dumitrescu, 1961, pp. 70–71, 80–81)—or deep in the Carpathians, as in Ariuşd (Makkay, 1995, p. 74; Fig. 3).

The most exceptional collection, however, comes from the cemetery of Varna I and includes c. 3100 gold objects (and 160 copper implements), weighing c. 6.5 kg in total (Biehl & Marciniak, 2000; Fol and Lichardus, 1988; Ivanov & Avramova, 2000; Leusch et al. 2017). The volume of the collection and the range of techniques applied in its production deserves special attention here. Out of 320 burials (inhumations, deposits, symbolic/cenotaph graves), around 70 contained gold artefacts ranging from one item to 990 objects (totalling 1.5 kg of gold) in a single burial, No. 43. Of 61 graves with gold artefacts, 34 were symbolic/cenotaph, 10 male, 13 female (?) and 4 disturbed (Biehl & Marciniak, 2000, p. 186). Leusch et al. (2017, p. 112, table 2) indicate cenotaphs as the richest graves, followed by male and then female burials. It is notable that no comparable range of prestige items and status markers has been found in adjacent settlements, which do not exhibit evidence for structural hierarchies or inequalities. Hence, scholars agree that the Varna cemetery served several local communities of an unspecified scale, rather than just a single settlement (Biehl & Marciniak, 2000; Chapman et al. 2006; Ivanov, 1988b; Lichardus, 1991a; Renfrew, 1978).

The Varna gold collection includes a range of decorative artefacts made of small beads, appliqués and sheets. Although made of native gold, the varying naturally-occurring concentrations of copper and silver in the golden nuggets exploited resulted in the golden objects having many different shades (Fig. 7d), ranging from white, via yellow, to light pink (Leusch et al. 2014, p. 175, fig. 11b). Overall, concentrations of silver range between 5 and 45%, and of copper between 0.05 and 2.5 wt% (Leusch et al. 2017). Leusch et al. (2016, p. 108, fig. 7.8) used the Pt/Pd ratio to discriminate between four different groups of gold in the Varna assemblage (300 objects analysed in total), which may be indicative of discrete geological resources, suppliers or workshops. While all of these scenarios require further research, the recent discovery of placer gold deposits near Varna

Fig. 7 A selection of gold objects from Varna. **a** Sheet-gilded copper bead from burial no. 41; **b** Gold bead from burial no. 4 with a hollow body made with lost wax casting technique; **c** The ring-idol from grave no. 271 is the earliest known gold-copper alloy (c. 50 wt% gold, 14 wt% silver, and 36 wt% copper); **d** Gold beads with different shades of gold due to the variable silver content. The silvery beads (top right) from grave no. 43 contain on average 58 wt% gold, 40 wt% silver, and 2 wt% copper (adapted after Leusch et al. 2014, pp. 167, 175, fig. 3a, 10b, 11a, b; c CC BY-NC-ND 4.0 by B. Armbruster and V. Leusch)

(Yovchev, 2014) points to the potential exploitation of regional resources at the time.

The artefacts buried in these graves include awls, chisels, cushion stones, stone adzes, flint scrapers, hammer-axes and antler tools. A sound case has been made that these might have been artisan's tools. The deposition of such items would emphasise the significance of artisans and crafting for the community at Varna (Leusch et al. 2017, p. 118). Anthropological analysis of one of the richest burials, No. 43, has shown that the male individual, between 50 and 65 years old, had pathological conditions related to squatting and hard work, in particular related to great robusticity of the lower arm muscle attachments, which suggests that this individual may have been an artisan or craftsperson (Leusch et al. 2017).

To further contextualise the paraphernalia related to crafts at Varna I, 122 out of 226 burials have items identified as tools that have never been used. These tools are as common as any other object deposited in the burials. Two potential imitations of objects are also present in the collection, adding to the assemblage of artisan tools: a copper pick (imitation of an antler pick?) and a golden 'penis sheath' (probably an imitation of a tuyère?) (Leusch et al. 2017, p. 107, Table 1). The latter is famously claimed to have been unearthed between the thighs of the individual in burial no. 43, which led to its interpretation as a penis sheath. However, its original position was beside the right thigh (Biehl & Marciniak, 2000, p. 186; Ivanov, 1988b, p. 55; Fig. 25; Leusch et al. 2014, pp. 168, 177, fig. 4a). An alternative interpretation that it was an imitation or gilding of a tuyère, however, has typologically close parallels with clay imitations from sites in Bulgaria (Kubrat, Goljamo Delčevo), Romania (Pietrele, Radovanu) and Serbia (Bubanj, Kmpije) (Fig. 4e–f) (Bulatović, 2015, p. 12, T.II/13; Comşa 1990; Hansen, 2009; Lichardus, 1988, 1991a, p. 174; Todorova, 1982). The idea of gilding is equally interesting, given that this golden object had two perforations at the base, indicating that it was stitched to another item, potentially as an ornament. Leusch et al. (2017, p. 114) claim that the item could not have been a tuyère imitation since the output vent has a wider diameter than in the clay models; nevertheless, imitations do not need to be exact copies. Finally, if the item was used as a foil decoration for clay tuyères, it would fit well with the practice of working with gold foil in the Varna cemetery (see Fig. 7a) (Leusch et al. 2015).

Careful examination of a total of 300 golden objects analysed within the Varna project (led by E. Pernicka) revealed different shaping techniques applied with hammers, punches and doming blocks, chisels used for chasing and parting, conical points for perforations, and sand, stones, ashes and siliceous plants used for finishing and polishing. Little is known, however, about the production debris of gold making. As is also true of the collection and consolidation of usable amounts of native copper, the exploitation of native gold would not produce any slags. Casting equipment required a similar set of tools to those needed for copper processing: crucibles, casting moulds, hearths and tuyères (Leusch et al. 2015). The exquisite craftsmanship required for making these objects is showcased using techniques borrowed from copper working, together with complex casting techniques to produce three of the world's first examples of alloying, gilding and lost-wax casting (Fig. 7a–c). A small group of gold–copper alloys was found to have copper content exceeding c. 30 wt%, which is significantly higher than the naturally occurring concentrations in native gold (Hauptmann et al. 2010) and implies intentional alloying (ring idol example in Leusch et al. 2014, p. 175, fig. 11a) (Fig. 7c). A copper bead from grave no. 41 was sheet-gilded (Fig. 7a) (Leusch et al. 2014, p. 167, fig. 3a), probably to produce the much sought-after golden colour, while a hollow and solid globular bead from another burial was produced using a lost-wax technique (Fig. 7b) (Leusch et al. 2014, p. 175, fig. 10b). This bead is the earliest known record of a lost-wax cast object, and pre-dates the spoke-wheel-shaped native copper amulet from the site of Mehrgarh (Pakistan) by as much as five hundred years (Thoury et al. 2016). The amulet came from the Early Chalcolithic horizon on this site, broadly dated between 4500 and 3600 BC, the authors settling on c. 4000 BC as the likely date for the emergence of lost wax casting in the far eastern end of the Iranian Plateau.

The mastery of gold production not only included the production of gold objects, but also extended to the decoration of non-metal objects (like pottery) with gold. Éluère and Raub (1991, p. 13) investigated the technology of gold coating on a large ceramic plate recovered from one of the rich Varna graves, and showed that its gold layer consisted of natural Au–Ag alloy with c. 7% Ag, and some copper. After coating, no polishing tools were used, presumably because this might have removed the gold. Éluère and Raub (1991, p. 19) speculated that wash (alluvial) gold dust was applied onto a plant glue which covered a ceramic surface in a process called sintering, which welded together particles without requiring a liquid stage (Raub, 1995, pp. 247–248). The tradition of decorating pottery with gold extends into the Krivodol–Salcuţa–Bubanj Hum complex in southwestern Bulgaria/southeastern Serbia, continuing well into the first centuries of the 4th millennium BC (Bulatović et al. 2018; Gajić-Kvaščev et al. 2012).

During the late 5th to early 4th millennium BC, the production of gold artefacts shifted towards the west Carpathian Basin, where gold pendants and decorations appeared within the late Tiszapolgár, Lasinja and Bodrogkeresztúr cultures (Dumitrescu, 1961, pp. 92–93). Gold ornaments of varying size were deposited as grave offerings in the cemetery of Tibava, in Slovakia (Šiška, 1964, p. 332) or in hoards, as at Moigrad, in Romania (Dumitrescu, 1961, p. 71; Fig. 3). Gold metal from this period amounts to a total of c. 5–6 kg of extant objects (Makkay, 1991, pp. 119–120); of these the most impressive is the heaviest golden object currently recorded from the Balkan Chalcolithic, a 31-cm diameter disc from the Moigrad hoard that weighs c. 800 g (Makkay, 1989).

Silver and Lead

Objects made of silver emerge in parallel to gold, although they are less common. Only a few pieces, of unknown context, originate from the Carpathians (Makkay, 1991), while in Greece hundreds of small items of silver jewellery have been found (Maran, 2000; Muhly, 2002). The richest find is a hoard from the Alepotrypa Cave (Fig. 3) in the Mani peninsula in Greece, dated roughly between the mid 5th and early 4th millennium BC (Muhly, 2002, p. 78; Papathanasiou et al. 2018); other sites with silver ornaments have been discovered on the islands of Crete and Lemnos. One of the large silver pendants from the Alepotrypa Cave has a distinctive shape—circular, with a central perforation and a pierced suspension tab—and has a slightly earlier golden counterpart in the cemetery of Varna. There is no contemporary evidence for silver production, with the earliest evidence for litharge fragments coming from Limenaria, Thassos and northern Greece, and dating to the early 4th millennium BC (Nerantzis et al. 2016; Papadopoulos, 2008).

The earliest processing of lead ore in the Balkans is documented at the site of Belovode, where a large slag 'cake' (Fig. 8) was recovered from an undisturbed and secure context associated with material datable to 5200 BC (Radivojević & Kuzmanović-Cvetković, 2014; Šljivar et al. 2012). Microstructural analysis conducted by the first author of this paper reveals well-formed—and once molten throughout—fayalitic slag with magnetite, matte inclusions and droplets of lead metal, which would have required temperatures in excess of 1100 °C to produce, and could not have been made by chance (Radivojević & Rehren, 2019). While there are no preserved lead objects known currently from this site, the only contemporary evidence in the broader 'Old World' sphere is the lead bracelet from layer 12 at Yarim Tepe I in Iran (Merpert & Muncaev, 1987). The results of chemical (qualitative) analyses conducted by E. N. Chernykh (Merpert & Munchaev, 1972) speak of pure lead metal as the base, some silver and traces of iron. This suggests the use of a lead ore of high purity, like galena, or perhaps native lead, which is very rare (Patterson, 1971). However, without an exact quantification of the silver content it is difficult to say which type of lead ore was used. Tylecote (1962, p. 76) reported that lead can be smelted easily from galena by a 'simple fire', which possibly refers to the melting point of lead at 328 °C. Interestingly, the wider Levantine and Northern Syrian region has produced some of the earliest known lead objects in the world, at least from the late 5th millennium BC onwards (cf. Yahalom-Mack et al. 2015).

The use of lead ore for making beads has also been documented at the Vinča culture sites of Autoput, Selevac, and Opovo in Serbia, and at Donja Tuzla in Bosnia, in all cases in horizons that end by 4500/4400 BC at the latest (Glumac & Todd, 1987; Quitta & Kol, 1969; Vogel & Waterbolk, 1963). As such, these artefacts, together with the lead slag, pre-date the use of lead ores at the site of Pietrele (set at c. 4400–4300 BC), erroneously claimed as the first and only evidence of lead ore processing in the Balkans (Hansen et al. 2019). The biconical crucibles in question are a very interesting find, and are apparently present in at least two Chalcolithic

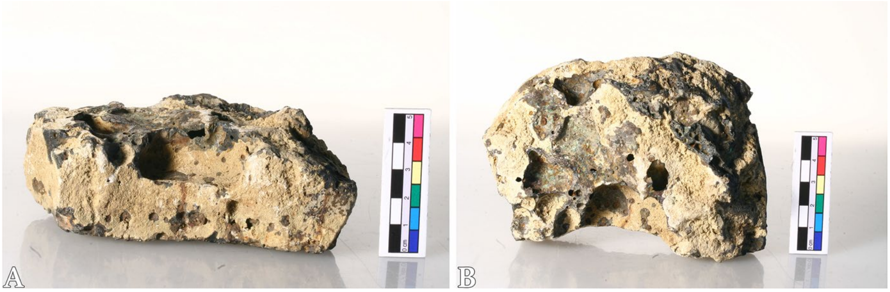

Fig. 8 Slag 'cake' from the site of Belovode, eastern Serbia, discovered in a context dated to 5200 BC. Compositional analysis revealed lead metal to be the likely product of the smelt (photo CC BY-NC-ND 4.0 M. Radivojević)

Romanian sites besides Pietrele: they are small biconical objects (c. 6 cm in diameter on average) with a narrow opening at the top, yet with inconsistent traces of heating when analysed across the whole assemblage. The purpose of these crucibles is yet to be resolved, as it remains unclear what smelting galena (PbS) in such a way produced. Hansen et al. (2019) dwell on the possibility of manufacturing a colouring agent such as yellow or red lead oxide. This would fit with the known practice of painting pottery in the Vinča culture (e.g. Gajić-Kvaščev et al. 2012; Mioč et al. 2004).

Miloje Vasić described two interesting situations that might have indicated the presence of smelting (lead) installations at the site of Vinča-Belo Brdo. The first refers to finds from 1913, when several ellipsoidal shallow pits were discovered within a small area at a depth between > 8.1 m and > 8.9 m (this translates into Vinča A phase in this settlement, c. 5300–5200 BC). The largest pit was 2.1 × 0.5 × 0.1 m in size (Antonović, 2002, pp. 35–36, note 60, fig. 3) and the pits had walls c. 8 cm thick, were intensely fired only in the centre and filled with soot and ash in the bottom. A galena bead was identified in the vicinity of one of these features. Similarly-shaped shallow installations were used for lead smelting in Vinča villages in the early twentieth century; this prompted Vasić to propose a similar function for these pits (cf. Antonović, 2002).

Copper Supply Networks

Analyses of metal objects and the large scale of copper production during the 5th millennium BC prompted Chernykh (1978b, 1992, 1997, 2008b, 2008a) to define the Carpatho-Balkan Metallurgical Province (CBMP) as a distinctive (and the earliest) technological and cultural entity from where metallurgical knowledge was carried eastward in staged migrations over the following c. 4000 years. His *metallurgical provinces* represent large interconnected systems of shared metallurgical technology, trade and exchange, which encompassed areas of up to a few million square kilometres across Eurasia, and which lasted for a few thousand years. On a practical level, they were linked through: (i) shared utilisation of morphologically defined ornaments and implements; (ii) common principles of metalmaking, with the availability of or access to the same ore resources; and (iii) comparable dating. Chernykh's (1992, p. 7) conceptualisation further makes the fine distinction between *metallurgical provinces* and *metallurgical foci*; the latter refers to smaller-scale regions where similar metal artefacts were produced by a group of skilled craftsmen over a certain period. The understanding of the extent of metallurgical provinces currently relies on the growing database of compositional analyses (nearly 120,000; see Chernykh, 2008a) and associated datable materials from between the Adriatic and the northern forests of Mongolia. As such, they are detached from the concept of culture and form part of larger-scale metallurgical provinces, which may encompass an area of up to eight million square kilometres, and endure over long periods of time.

The CBMP included several cultural phenomena in the northern Balkans and the Carpathian Basin related to the emergence and spread of copper metallurgy during the 5th millennium BC, and most notably around the mid 5th millennium BC, which is defined as the ‘metal boom’ phase by Chernykh (1978b, 1991, 1992). This province spanned c. 1.3–1.4 million km^2 at the peak period of metal production. Chernykh (2008b, p. 76) distinguished three groups of the 5th and early 4th millennium BC metal-producing and consuming cultures. The first, ‘core’ group (Butmir, Vinča C/D, Lengyel, Karanovo V–Maritsa, KGK VI, Varna, Tiszapolgár, Bodrogkeresztúr cultures, see also Fig. 10), broadly includes the central, eastern and northern Balkans and spans over five hundred years across an area of 0.75–0.8 million km^2. A second group is represented by the Tripolye–Cucuteni culture, which extended from the Carpathian Mountains to the Dniester and Dnieper regions, with centres in modern-day Moldova and western Ukraine, and occupied c. 0.16–0.18 million km^2, while a third group consists of communities occupying the steppes to the north and north-east of the Black Sea coast.

Archaeological cultures throughout the CBMP display technological similarities in several respects: the set of product classes and types; metalworking technology; and metal composition (pure copper) (Chernykh, 1978b, 1992; Ryndina & Ravich, 2000, 2001). The most recent technological and metallographic study showed that the massive copper implements from the Vinča culture sites of Pločnik were worked in the same way as those from KGK VI and Varna sites in north-eastern Bulgaria (Radivojević, 2012), confirming the existence of a shared technological principle (or recipe) for metalworking across the Balkans, in place from the very beginning of the 5th millennium BC. Radivojević (2012) further observed that the shared metallurgical tradition, mirrored in the specific technique for finishing the massive copper implements across the Balkans, reveals that the network of metalsmiths was resistant to various cultural collapses (like Vinča or KGK VI), and that it probably existed outside the remits of archaeological cultures as defined by distinctive material traits. Subsequent study and publications relating to the invention, innovation and cultural transmission of metallurgical knowledge in the 5th millennium BC Balkans (Radivojević, 2015; Radivojević & Kuzmanović-Cvetković, 2014; Radivojević & Rehren, 2016; Radivojević et al. 2013a, b) support the logic of Chernykh’s original concept of the *metallurgical province* as an entity independent of particular cultural phenomena, and highlight shared technological knowledge. We see it as the key to understanding the social dynamics of this period; however, this concept needs further interrogation in relation to (extractive) production and all aspects of the metallurgical *chaîne opératoire* to allow us to better interpret the nuanced detail of knowledge transmission.

Extensive programmes of compositional analysis indicate that 5th millennium BC metal artefacts in the Balkans were made of almost pure copper (e.g. Chernykh, 1978b; Junghans et al. 1968; Pernicka et al. 1993, 1997; Radivojević, 2012; Radivojević & Grujić, 2017, 2018: table S1); this is why the trace element signature, along with lead isotope analysis, has proved particularly useful for indicating plausible sources of metal. Provenance (lead isotope and trace element) analyses of several hundred copper artefacts from the mid-to-late 5th millennium BC indicate the use of local Balkan sources, amongst which the signature of Ai Bunar was predominant (Pernicka et al. 1997, p. 117, fig. 20, table 3). All copper artefacts analysed by Pernicka et al. (1997) were assigned to ten distinctive lead isotope grouplets, each relating to a particular deposit, a group of spatially tight deposits, the same geochronological unit (not necessarily spatially close) and even a grouplet of artefacts not associated with any known source (Grouplet #7, or 'Group of 16', see below). These grouplets are therefore not sufficiently well characterised to allow predictions of the exact location of origin of the smelted metal. The information on grouplets is then paired with that for clusters (derived from clustering of trace element signatures), and used together with archaeological information to ensure the best estimate of metal provenance (Pernicka et al. 1997). Given the widespread presence of copper metal implements from various copper deposits across this region, we may assume that these local sources were shared among different cultural groups. There is, indeed, a prevalence of KGK VI material culture in the ancient mines of Ai Bunar; however, the distinctive chemical signature of this source is found in nearly one quarter of Middle–Late Chalcolithic copper objects analysed thus far.

Another distinctive provenance signature is ascribed to Majdanpek in eastern Serbia, although this deposit was more intensively exploited in the Early and Final Chalcolithic. Pernicka et al. (1997) observed large shifts in copper supply throughout the Balkan Chalcolithic in the provenance data. For example, analysis of copper in a significant number of artefacts dating to the first half of the 5th millennium BC shows that it originates from the Majdanpek lead isotope field; this metal is almost absent from the Middle and Late Chalcolithic artefacts, but again becomes a dominant source in the Final Chalcolithic (Pernicka et al. 1997, p. 106). These changes go hand in hand with the known cultural dynamics at the time: the use of eastern Serbian sources decreases sharply with the end of the Vinča culture, while the exploitation of Ai Bunar and other Bulgarian deposits (such as Medni Rid) intensifies with the rise of the KGK VI, Varna and Krivodol–Salcuţa–Bubanj Hum cultural phenomena. As noted above, the collapse of these cultures—commonly ascribed to an environmental catastrophe (Weninger et al. 2009) but remaining the subject of considerable debate (see Tsirtsoni, 2016a)—was followed by a resumption of more active use of the eastern Serbian deposits and the subsequent appearance of the Bodrogkeresztúr phenomenon.

The recent addition of provenance analysis of Vinča culture archaeometallurgical materials from Radivojević (2012) and *The Rise of Metallurgy in Eurasia* project (Radivojević et al. in press) offers a more nuanced understanding of the dynamics of copper supply networks during the 5th millennium BC in the Balkans. The Early Chalcolithic period appears to be dominated by copper from sources in eastern Serbia, such as Majdanpek, Ždrelo, and at least three other, as yet unidentified, deposits. These are: a) a copper deposit with Co/Ni rich mineralisation (potentially in the vicinity of Rudna Glava); b) Grouplet 7 (or 'Group of 16'), an assemblage of 16 Chalcolithic copper metal implements with a unique lead isotope signature discovered mostly along the lower Danube (Pernicka et al. 1997, p. 89); and c) Cluster 8, composed of 13 copper metal implements, two slag samples and two malachite beads from the sites of Belovode, Selevac, Pločnik, Durankulak, Gomolava, Daržanica, Hotnica and Zlotska pećina, all with chemically close trace element pattern (cf. Pernicka et al. 1993, 1997, pp. 93–94, 105–106, table 3; Radivojević et al. 2010b). Bulgarian sources, like Ai Bunar, became active only towards the mid 5th millennium BC, and are associated with the earliest copper implements from southern and north-eastern Bulgaria (Chernykh, 1978a; Pernicka et al. 1997, p. 93, table 3), and copper implements from the last phase of the site of Pločnik (c. 4400 BC) (Radivojević et al. in press). Medni Rid in southeast Bulgaria also supplied the Middle/Late Chalcolithic, almost exclusively for the east Balkan settlements (Kunze & Pernicka, 2020; Rehren et al. 2021). An important point arising from the available provenance data is the existence of multi-producer and multi-consumer networks of copper from the early stages of metallurgy development, in which the most connected 'nodes' are the Vinča culture sites with evidence for metalmaking and working, and settlements located along the lower Danube (Durankulak, Ruse).

More recently, Radivojević and Grujić (2018) developed a unique approach to investigating the networks and dynamics of copper supply between c. 6200 BC and c. 3200 BC, based on the currently available datasets from Pernicka et al (1993, 1997), Radivojević (2012) and Radivojević et al. (in press), including 410 copper-based objects from 79 sites (all made freely available in table S1 in Radivojević & Grujić, 2018: also available at: https://www.repository.cam.ac.uk/handle/1810/265760). The authors applied a complex networks approach, using a modularity maximisation method (Blondel, 2008) in order to explore the structure of the most densely connected sites through the strength of copper supply, trade or exchange links. They identified three highly interconnected systems—community structures or 'modules'—composed of supply networks that reflect organisation of the copper industry and, effectively, social and economic ties in the Balkans between c. 6200 BC and c. 3200 BC (Radivojević & Grujić, 2018, p. 116, fig. 6). The intensity of algorithmically calculated social interaction revealed three main groups of communities that appeared as spatiotemporally and statistically significant: the resulting structures held a strong resemblance to at least three dominant economic and social cores of copper industry in the Balkans across about three thousand years, traditionally defined as Vinča, KGK VI and Varna, and Bodrogkeresztúr (Figs. 9a–f, 10a–f). Importantly, the complex interlinking topologies of these three modules were quantified independently of cultural, chronological and geographical attributes.

Besides suggesting spatiotemporal patterning, this resemblance showed that algorithmically calculated community structures currently represent the most precise mathematical model available for identifying such archaeological phenomena: the dynamics of copper exploitation, production and consumption practices reflected closely those of recorded social interactions for the time and region studied. Although Radivojević and Grujić (2018) did not suggest that metallurgy-related practices were the sole factor in defining interactions such as collapses or rises of cultural complexes, their research indicates that these industries must have been sufficiently powerful to play a major role in their shaping.

Radivojević and Grujić (2018) also observed the selective formation of network ties amongst site populations in relation to both specific regional copper sources (e.g. eastern Serbian Majdanpek, central Bulgarian Ai Bunar) and communication routes (e.g. lower Danube), as well as their association with either seemingly 'monopolised' (e.g. Bodrogkeresztúr in Fig. 11c, d) or 'open-market' (e.g. KGK VI in Fig. 11c, d) organisation of copper supply networks across the periods analysed. These results are consistent with previous research on metal provenance in the Balkans (Pernicka et al. 1993, 1997; Radivojević, 2012). Importantly, this study also indicated an overall tendency for communities identified as archaeological cultures

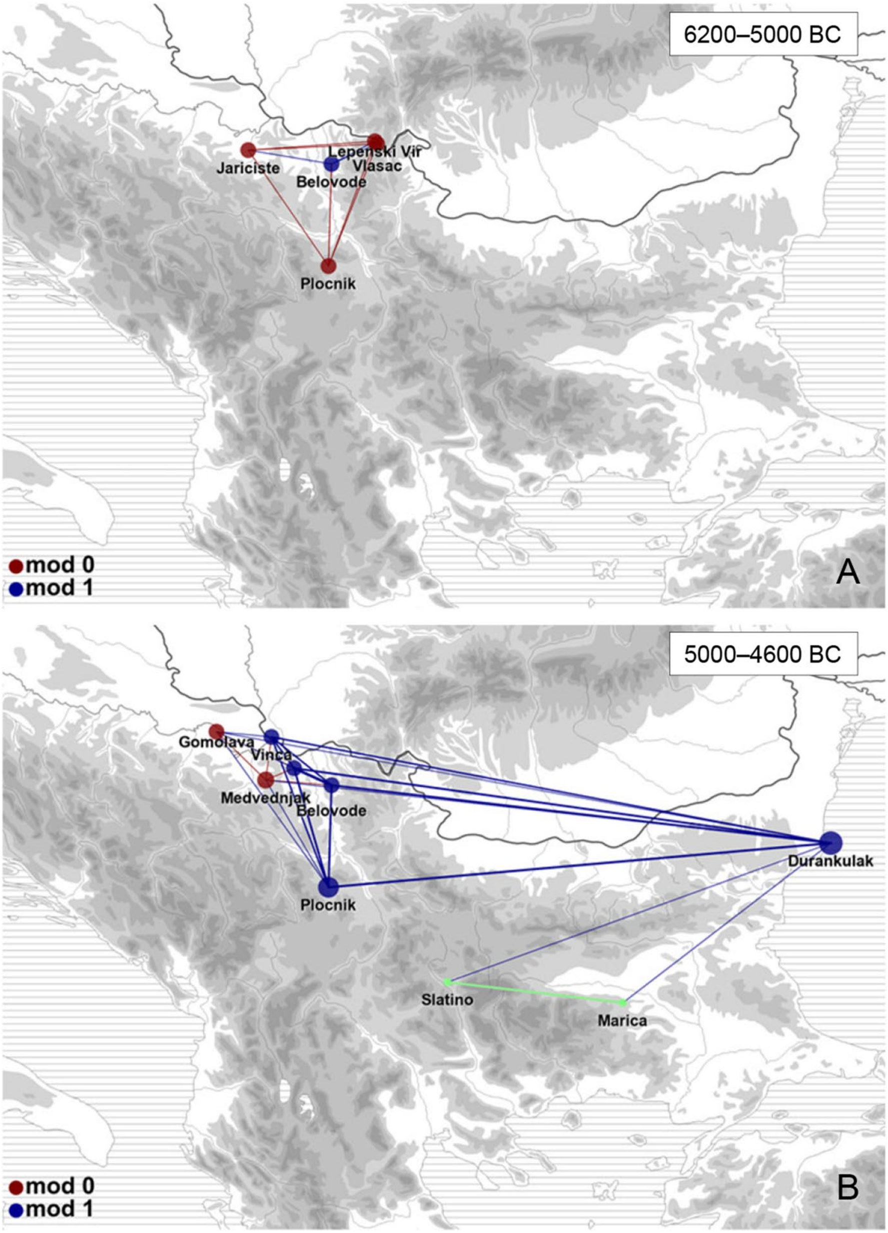

Fig. 9a, b Networks of copper supply in the Balkans 6200–3200 BC (*full sequence Figs. 9a–e*). **a** the period 6200–5000 BC illustrates the early core of supply networks for copper mineral-only artefacts; **b** the period 5000–4600 BC is dominated by the supply networks of Module 1 (a proxy for the Vinča culture, see Fig. 10) (after Radivojević & Grujić, 2018, fig. 6)

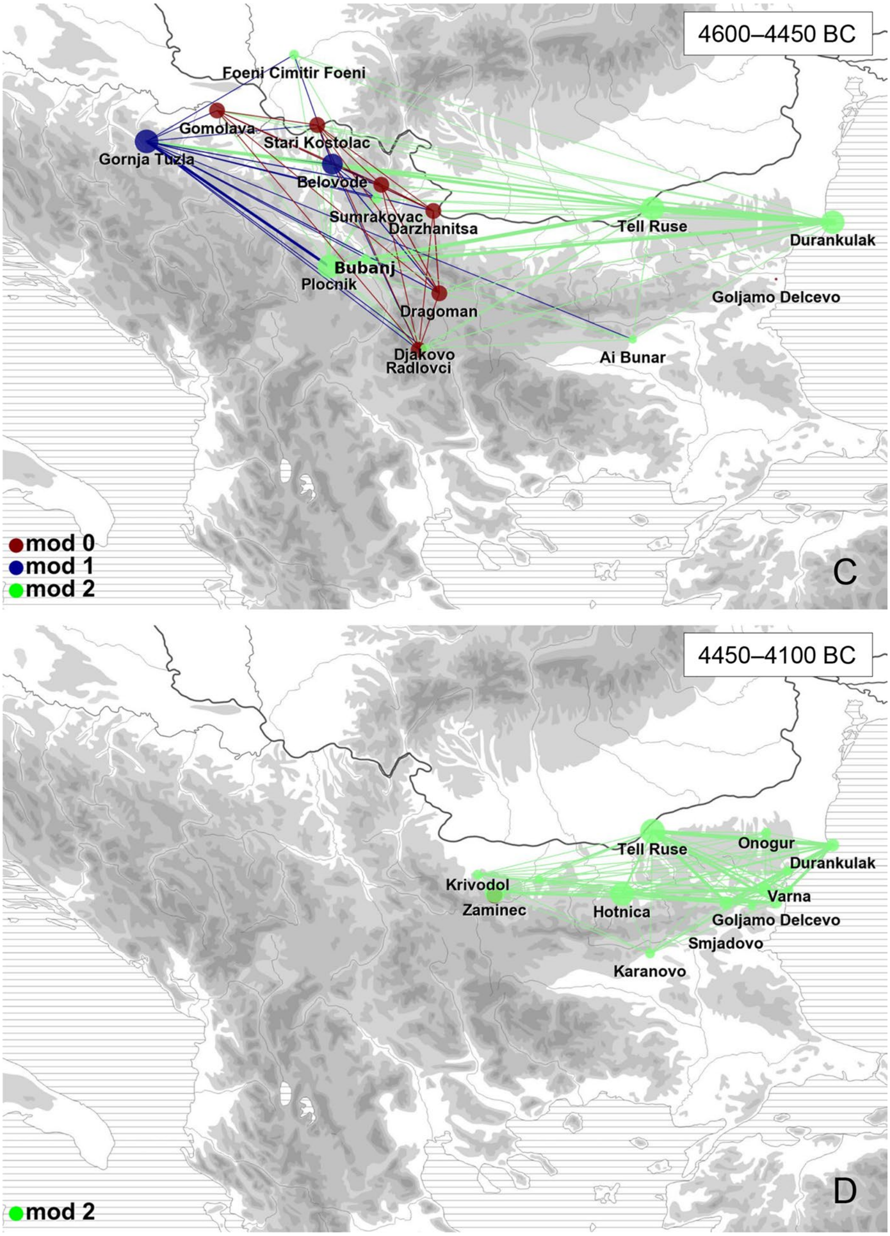

Fig. 9c, d Networks of copper supply in the Balkans 6200–3200 BC (*Fig. 9 continued*). **c** the period 4600–4450 BC is dominated by the developing Module 2, which emerged in parallel with the slowly disappearing regional supply networks of Modules 0 and 1; **d** the period 4450–4100 BC demonstrates the predominance of Module 2 in the east Balkans (a proxy for the Kodžadermen-Gumelniţa-Karanovo VI cultural complex, Fig. 10) (after Radivojević & Grujić, 2018, fig. 6)

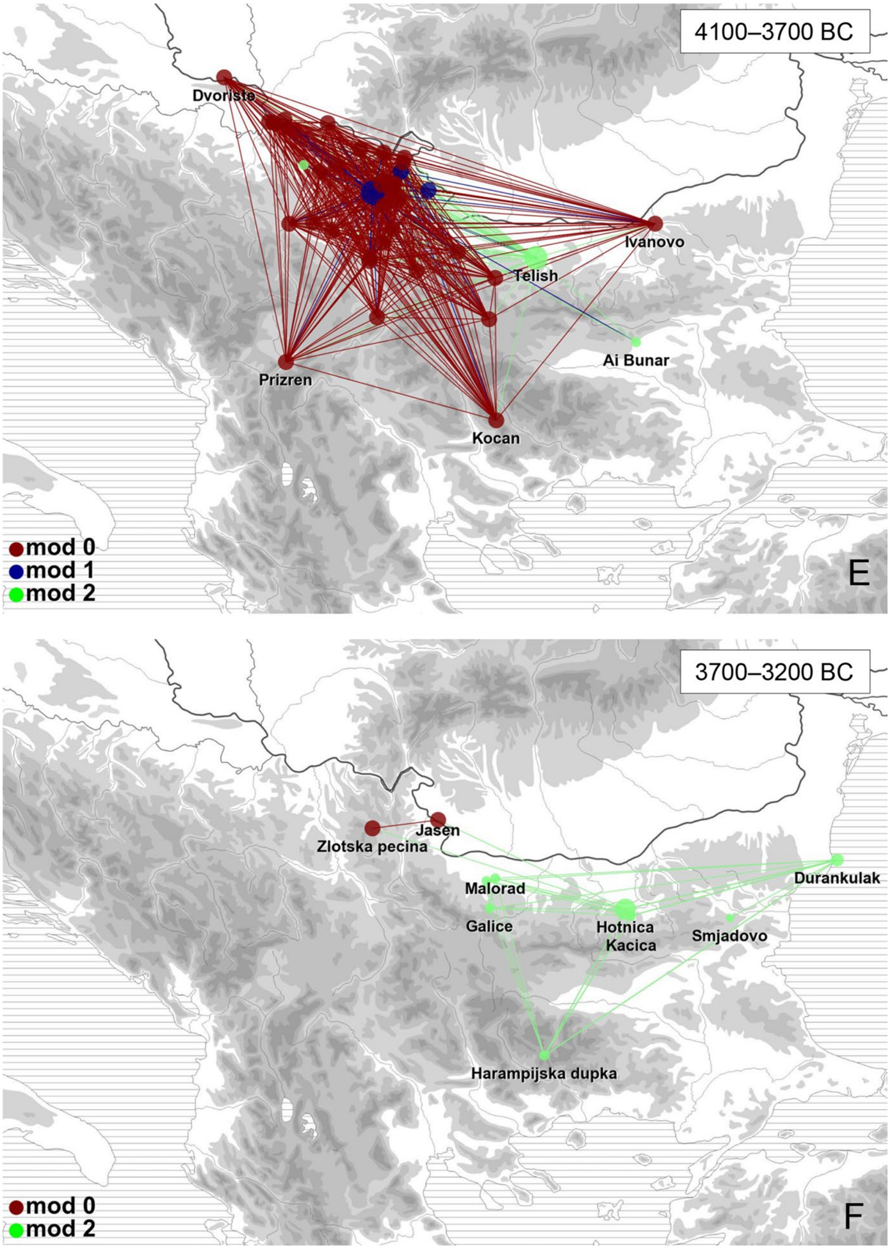

Fig. 9e, f Networks of copper supply in the Balkans 6200–3200 BC (*Fig. 9 continued*). **e** the period 4100–3700 BC shows the rise of supply networks of Module 0 in the Central Balkans (eastern Serbia, a proxy for the Bodrogkeresztúr culture, Fig. 10) following the collapse of the eastern Balkan networked systems by 4100 BC; **f** the period 3700–3200 BC presents a picture of nodes scattered in the eastern Balkans, which together reflect an incoherent set of available data (after Radivojević and Grujić 2018, fig. 6)

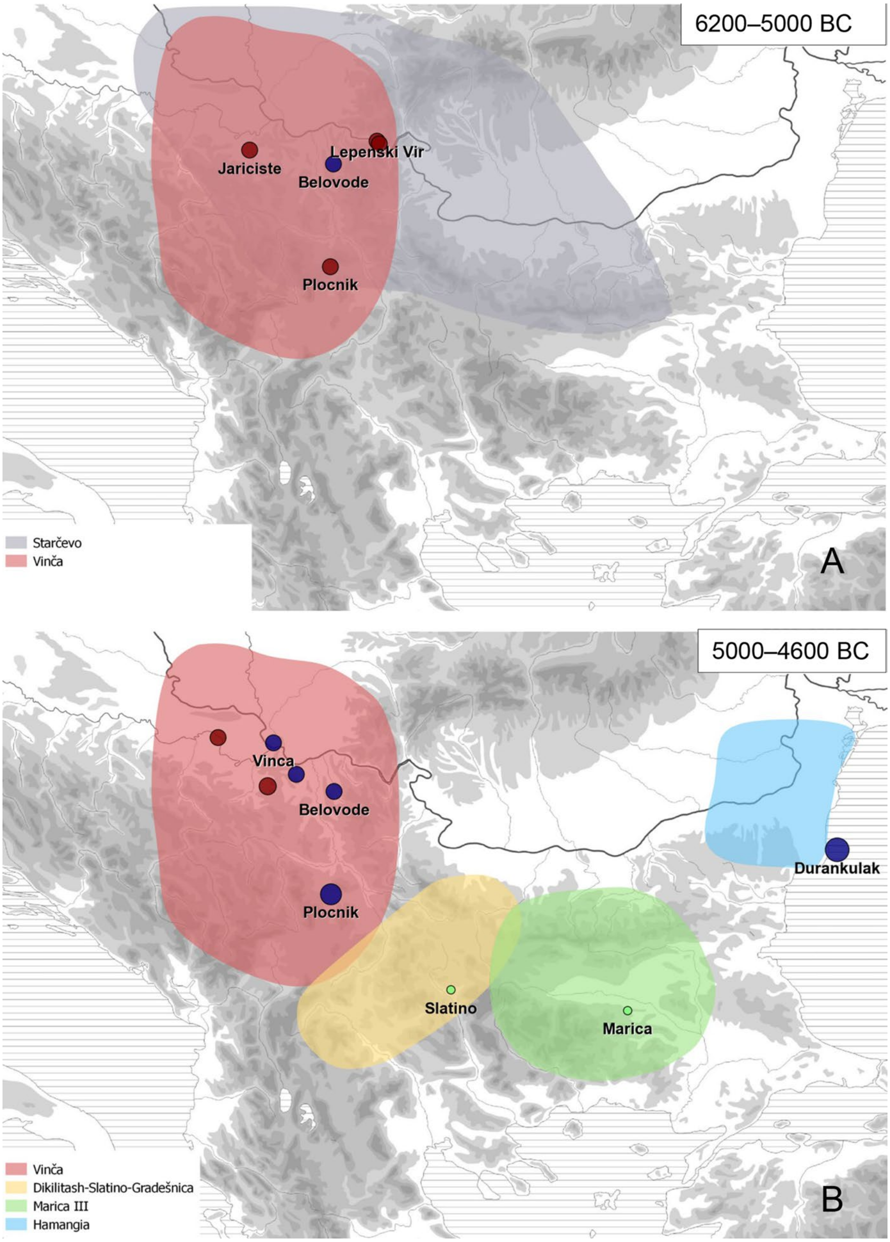

Fig. 10a, b Distribution of archaeological cultures/copper-using societies in the Balkans 6200–3200 BC (*full sequence Figs 10A–E*). **a** 6200–5000 BC; **b** 5000–4600 BC. The maps show the most relevant sites; note colour-coding and size of nodes consistent with the module colour (Module 0: red, Module 1: blue, Module 2: green) (after Radivojević and Grujić 2018, fig. 7). (Color figure online)

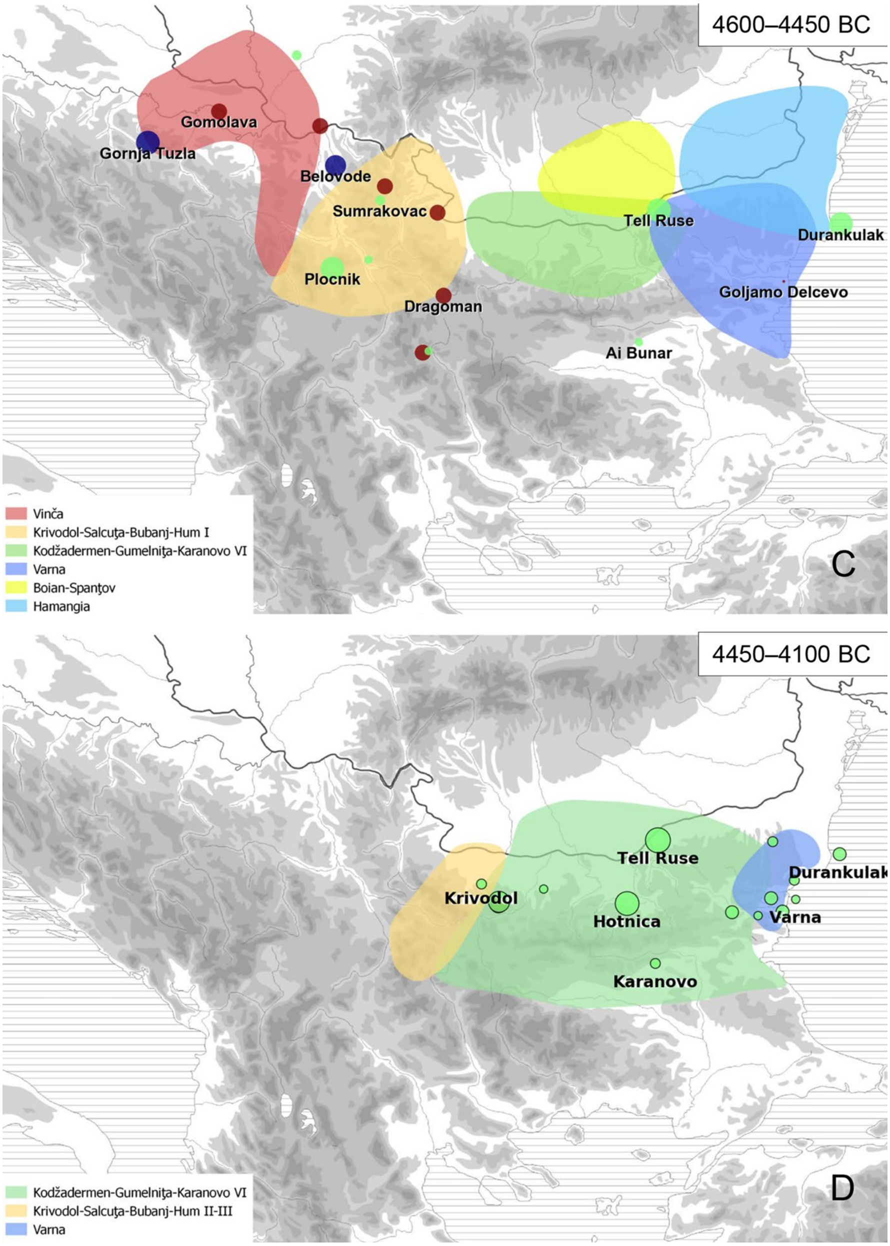

Fig. 10c, d Distribution of archaeological cultures/copper-using societies in the Balkans 6200–3200 BC (*Fig. 10 continued*). **c** 4600–4450 BC; **d** 4450 BC–4100 BC. The maps show the most relevant sites; note colour-coding and size of nodes consistent with the module colour (Module 0: red, Module 1: blue, Module 2: green) (after Radivojević and Grujić 2018, fig. 7). (Color figure online)

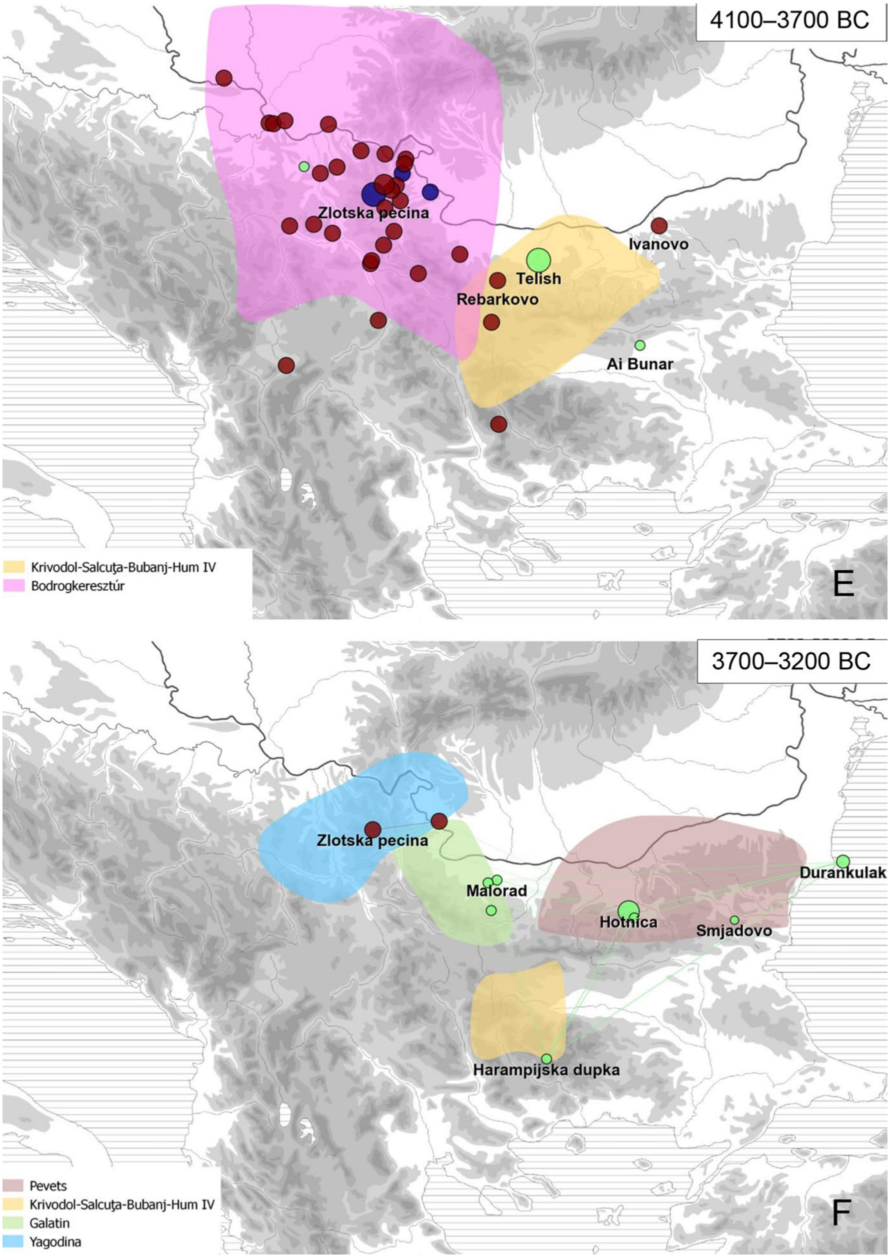

Fig. 10e, f Distribution of archaeological cultures/copper-using societies in the Balkans 6200–3200 BC (*Fig. 10 continued*). e 4100–3700 BC; f 3700 BC–3200 BC. The maps show the most relevant sites; note colour-coding and size of nodes consistent with the module colour (Module 0: red, Module 1: blue, Module 2: green) (after Radivojević and Grujić 2018, fig. 7). (Color figure online)

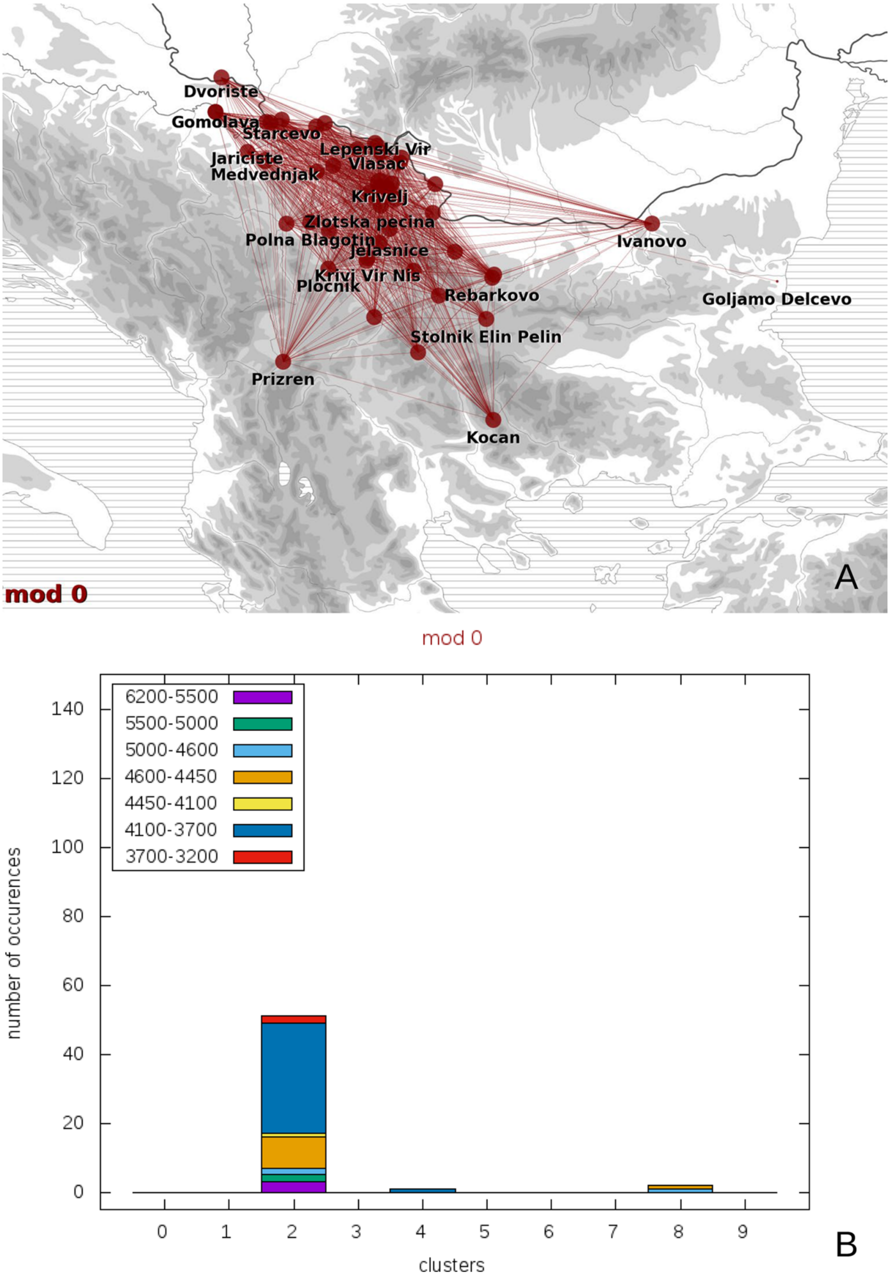

Fig. 11a, b Modularity structures of copper producing and exchanging communities in the Balkans 6200–3200 BC (*full sequence Figs. 11A–E*). Each map is paired with a diagram illustrating the frequency of ten different chemical clusters within the module. Module 0 is represented with 50.5 % of nodes in the total network and three chemical clusters only, of which No. 2 is predominant and covers c. 6200–3200 BC (after Radivojević & Grujić, 2018, fig. 5)

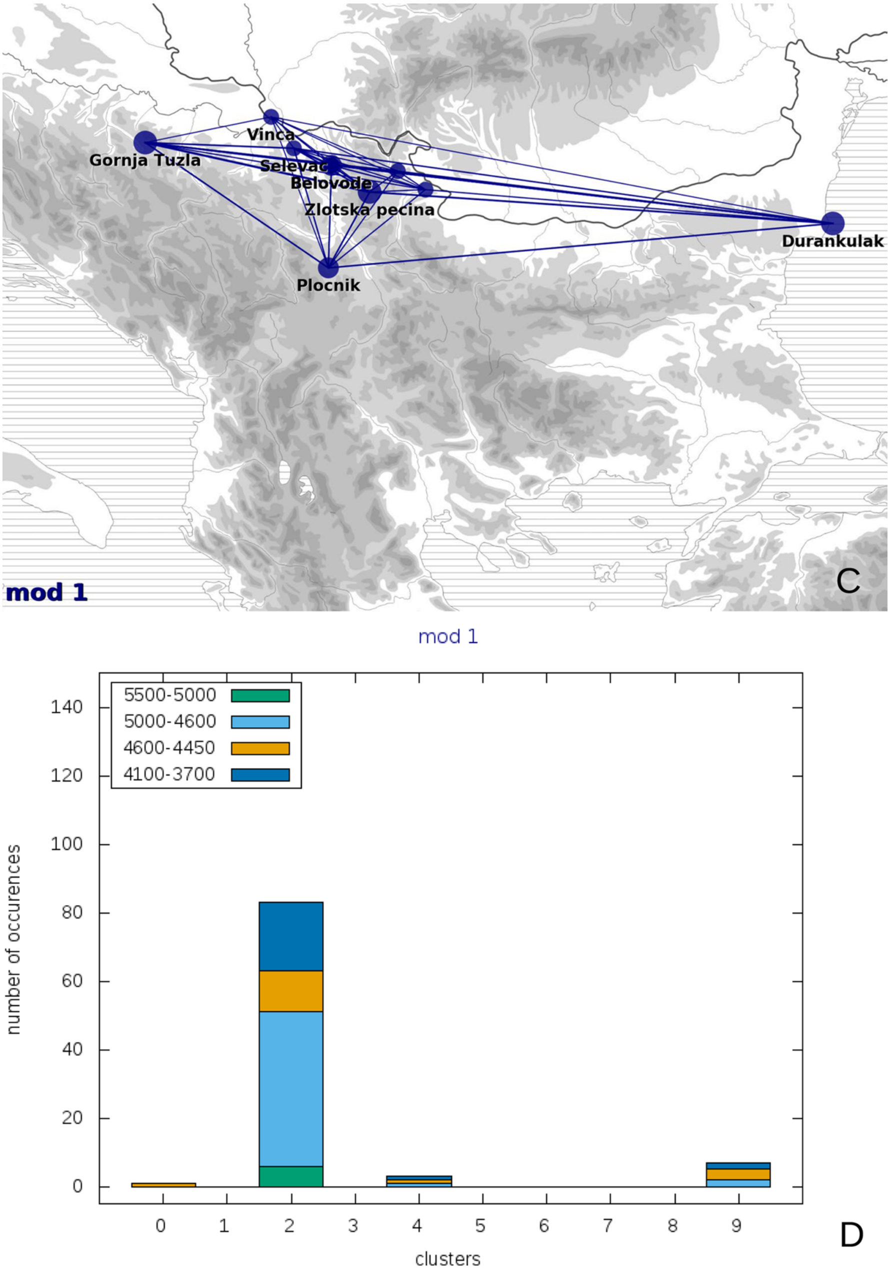

Fig. 11c, d Modularity structures of copper producing and exchanging communities in the Balkans 6200–3200 BC (*Fig. 11 continued*). Module 1 is represented with 11.8 % of all nodes and four chemical clusters. Within the chronological spans 5500–4450 BC and 4100–3700 BC, chemical cluster No. 2 is the most dominant, while clusters 0, 4 and 9 have a minor presence (after Radivojević & Grujić, 2018, fig. 5)

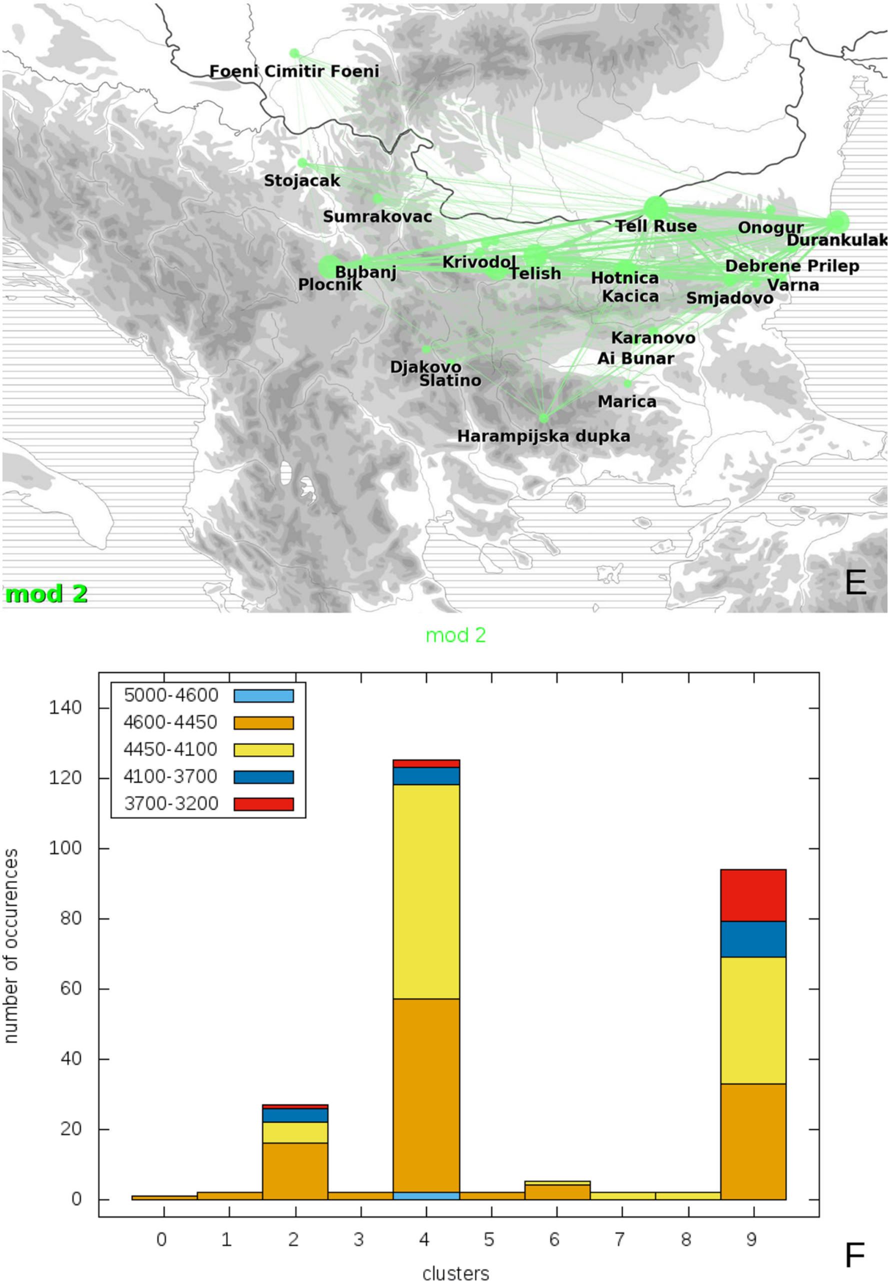

Fig. 11e, f Modularity structures of copper producing and exchanging communities in the Balkans 6200–3200 BC (*Fig. 11 continued*). Module 2 includes 37.6% of nodes in the total network and includes all ten chemical clusters (0–9). Chronologically it covers the period between 5000 and 3200 BC, with two divisions (4600–4450 BC and 4450–4100 BC) together representing 85% of all artefacts in this module (after Radivojević and Grujić, 2018, fig. 5) to maintain their own regional network of copper exploitation, production, exchange and consumption. In this light, metal recycling practices are plausible, although they may have happened within specific regional networks of copper supply (or 'modules'). In such cases, recycling would not be easily identified in provenance analyses, as this activity homogenises the metal pool—and if the metal were coming from a single source or deposit, the signature would stay the same regardless of the reuse or recycling process.

This is not to say that modules or archaeological phenomena identified in this way represent past socio-economic formations or ongoing communities that did not cooperate amongst themselves. Quite to the contrary, there were links (see Figs. 9a–f, 11a–f) *between* the modules, even though these were not as strong as those *within* them. Knowledge of metalmaking spread through these links across the Balkans from the Vinča culture 'core': it expanded and collapsed along with the rise and fall of the cultural complexes, but it never ceased to be practised. Although the dataset dated younger than 3200 BC was not targeted in the networks research, we are aware of continuing metalmaking practices at the fringes of the 'core' metallurgical area: the western Balkans, eastern Alps, Slovakian Alps, Carpathians (both Transylvania and Moldova) and well into the Caucasus Mountains, all arising during the early-to-mid 4th millennium BC with copper and arsenical copper production (e.g. Antonović, 2014; Bognár-Kutzián, 1972; Courcier, 2014; Dolfini, 2014; Hansen, 2013b; Höppner et al. 2005; Novotna, 1970; Radivojević et al. 2010a; Roberts et al. 2009; Ryndina & Ravich, 2012; Vulpe, 1975).

Recent detailed re-evaluations of the transmission of metal artefacts and metallurgy from the Balkans westwards into Central Europe and the Central Mediterranean (Dolfini, 2013, 2014; Rosenstock et al. 2016; Scharl, 2016) highlight the earliest appearance of copper artefacts in both regions from c. 4600/4500 BC, with a subsequent increase in metal circulation and consumption, culminating in a marked intensification of local metal production in both regions from c. 3900/3800 BC. As Rosenstock et al. (2016) demonstrate clearly in their temporal and spatial analyses of early metal objects spanning a region from Scandinavia to Iran, the periods c. 4000–3800 BC, 3800–3600 BC and 3600–3400 BC each see significant fluctuations in the densities of metal artefacts. They argue that between 5000 and 3400 BC there is a strong correlation between the presence of early metal objects and the density of settlement occupation (and implied population densities). The paper also notes that, while relating metal artefacts to settlement densities is a significant advance, relationships between the communities living in the settlements that produced, traded and consumed the metal objects must be assumed. It is only through the novel application of networks (modularity) analysis to the metallurgical data (as discussed above) that we are able to demonstrate that it is primarily the cooperative links between communities—rather than simply the density of population—that shapes metallurgical innovation, production and consumption (cf. Radivojević & Grujić, 2018). Yet, it is clear from all of these papers that the antiquated scholarly tradition of seeking to present the metallurgy of the mid 5th millennium BC or the mid 4th millennium BC across the Balkans (and/or the neighbouring regions) in the broad, dramatic narratives of 'watersheds' and 'heroes' (cf. Hansen, 2013a, 2014) overshadows the analytical and interpretative potentials of the current evidence.

Of Metallurgy and Metallurgists

The relationship between early metallurgy, metallurgists and societies in the Balkans has been the subject of extensive and wide-ranging scholarship (e.g. see review in Kienlin, 2010). This has invariably concentrated upon the proposed significant impact of metallurgy on the societal themes of social complexity and craft specialisation, especially in relation to the emergence or (self-)identification of elites, as producers and/or consumers, across the region. The evidential basis for the ensuing debates tends to centre upon the cemetery site of Varna, Bulgaria, which rapidly came to be considered the type site demonstrating the relationship between early metallurgy and a high level of social differentiation (e.g. Ivanov & Avramova, 2000; Renfrew, 1978, 1986). While there is no doubt that there are substantial differences in the treatment of individuals across the Varna cemetery, as discussed earlier (see Krauss et al. 2017; Krauss, Zauner and Pernicka 2014), there have been few cemeteries excavated in the Balkans dating to c. 5000–3700 BC that are of comparable size (e.g. Durankulak, Bulgaria) (Todorova, 2002), and none that are comparable in metallurgical, or indeed material, extravagance in their grave goods, especially beyond north-eastern Bulgaria (Lichter, 2001). Similarly, in terms of craft specialisation, the techniques of gold production at Varna, such as gold alloying, lost-wax casting and gilding, are technologically unparalleled across the Balkan region (cf. Ivanov, 1988a; Leusch et al. 2015; Leusch, Pernicka & Armbruster, 2014), and beyond. While not wishing to diminish either the site of Varna or the related research, the quantity and quality of the metal evidence has completely overwhelmed ongoing and, indeed, increasingly circular, debates on early metals, elites and social complexity in the Balkans (e.g. 2013b; Hansen, 2012; Kienlin, 2010; Kienlin & Zimmermann, 2012).

Beyond Varna, it is the sheer quantity of copper known to have circulated in the Balkans that is drawn upon when relationships between metals and societies are explored. Ryndina (2009) estimated that the amount of metal circulating in the region translates into c. 4300 artefacts while Chernykh (1992) proposed 4.7 tonnes. The amount of extant copper metal artefacts discovered across the 5th millennium BC Balkans outweighs the contemporary mining and production evidence. Apart from the beads, fish-hooks and awls already known from the late 6th millennium BC, this period witnessed an explosion in the production of massive copper implements, such as hammer-axes, chisels and bracelets, from the very beginning of copper smelting practices at c. 5000 BC. However, the various calculations, artefact discoveries and distributions need to be considered with caution as the number of extant copper implements in the Balkans may represent specific depositional or recycling practices (see Chapman & Gaydarska, 2020; Taylor, 1999). This is certainly highly significant when contrasting with the evidence for metal artefacts known from the European and Near Eastern Bronze Ages (Radivojević et al. 2019), and potentially also earlier.

The elevated interpretative status of the metal objects in the Balkans is invariably justified by the distinctive forms produced together with their material properties of hardness, lustre and colour. Societies across the Balkans in the 5th millennium BC display a preference for brilliance, colour aesthetics, precision, and geometric thinking, which dominates the material culture of the time more broadly (Chapman, 2011), and which has its roots in the Mesolithic period in the region (Chapman & Richter, 2009; cf. Srejović, 1972). Well-executed craftsmanship, bold colours, dramatic shapes and symmetrical design can be encountered combined in single objects in the 5th millennium BC Balkan material culture. For instance, a high degree of standardisation is seen in the production of flint blades from the Bükk culture (Vértes, 1965); remarkable geometric precision is present in the pottery of the Cucuteni–Tripolye culture (Washburn & Crowe, 2004); spectacular craftsmanship in displayed by the gold-decorated vessels in the Varna I cemetery (Ivanov, 1988b); and outstanding painting techniques are present in the silver sheen of graphite-painted pottery of the KGK VI cultural complex, and beyond (Todorova & Vajsov, 1993).

If we are to revise our interpretations of early metallurgy and metallurgists then we need to build these interpretations from all the available and relevant data, gathered and analysed by new and innovative approaches, but we must also acknowledge and critically evaluate the existing narratives that dominate the discourse.

The earliest known evidence for metallurgy occurs in the central Balkans and dates from c. 5000 BC. However, these few fragments of copper smelting slag from Belovode do not represent some unique ‘eureka’ moment. Rather, they represent the consequences of a sustained process of invention in the Balkans that can be traced from c. 6200 BC (Radivojević, 2015), with the careful selection of copper minerals on the basis of their colour and, from c. 6600 BC, with the pyrotechnology of ceramic production (de Groot, 2019). However, it remains difficult to identify what kind of ceramic pyrotechnological knowledge—if any—influenced the emergence of copper smelting. Amicone et al. (2020b) acknowledge that black burnished pottery was potentially a route to mastering firing techniques, but the very technique that connects the pyrotechnology of metallurgy and that of the pottery seems to emerge in both crafts at around the same time. The selection of lead ores and the application of pyrotechnology to them, evidenced from c. 5200 BC in the central Balkans, is too often overlooked. It is, however, evident that the knowledge, the pyrotechnological experiments, and the establishment of craft and material practices surrounding vibrantly coloured minerals and, subsequently, ores, whose metallurgical properties could only have been distinguished by their colours (black, green, blue and violet), were fundamental during the centuries spanning c. 6200–5000 BC.

What, then, did the copper smelting process look like in the first five hundred years of this practice in the Balkans, based on current analytical and field evidence? In the absence of any other smelting installations, the current model of metal production inferred from the hole-in-the-ground ‘furnaces’ (cf. Radivojević & Rehren, 2016; Rehren et al. 2016) speaks to the large quantity of extant copper metal artefacts being produced in multiple individual episodes. These smelting episodes could have been made more efficient if many were undertaken simultaneously, within one or more households (or, more precisely, within one or more of the backyards of individual dwellings, as this was an outdoor operation [Radivojević et al. in press). The production efficiency would depend upon the smelting charge (ores plus fuel) and the ability to maintain the redox conditions. While the final results could be anywhere between tens and hundreds of grams of copper metal, it is unlikely, based on the current evidence, that the heavier (1 kg plus) copper implements were produced in a single smelt. The fragmentary evidence of melting (?) crucibles in Bulgaria and, possibly, Romania speaks to this metal being remelted and cast (Koukouli-Chryssanthaki et al. 2007; Rehren et al. 2021; Stefan, 2018). We can observe evidence for the latter only from metallographic examination of as-cast objects (Kienlin, 2010).

In 2013, during the excavation campaign at Pločnik, the first author ran a series of smelting experiments based on these early reconstructions of the metal extraction process, and managed to successfully smelt copper from local ores with her team. One clear outcome of these experiments (the full account is currently outside the remit of this paper) is that, in order to be successful, the process demands a community of people working together in a range of co-ordinated roles (Fig. 12). Six people were required to operate six blowpipes with ceramic nozzles on their tips (see Fig. 4e–f). These individuals were constantly changing, as fresh blowers were needed every 15–20 min in a process that, on average, lasted 60 min. Meanwhile, a seventh member of the smelting crew ('master smelter') was engaged in maintaining the fire or regular charcoal charge. An additional, and critical, member of the team was, strangely enough, a drummer. Well-paced and uninterrupted air blowing into the 'furnace' was crucial for the success of the smelt, ensuring that the desired temperature was reached at a rate that prevented the copper metal ending up in the slag. With a large group of people participating, it was impossible to maintain the air flow without a unifying rhythm. That this set-up is a good solution is also known from experimental reconstructions of African iron smelting, where drums are used to signal the rhythm needed for the effective use of bellows (cf. Chirikure, 2010; Humphris et al. 2018).

These smelting experiments prompt us to consider how the control of smelting knowledge was exerted, and how the personal relationships between the many participants may have shaped the smelting technology. They also raise the question of how strict the replication of the 'recipe' could be in this environment, and whether the variations that we see in the composition of colourful ores used for copper smelting (Radivojević & Rehren, 2016) could be explained by human factors, such as trial and error. Furthermore, how was trust developed and what kind of ties or rituals connected the participants in the metal production process? In the absence of any indication that this was a full-time occupation, were they all members of a specific group within a community which co-operated for metallurgy (a 'cooperative'), or simply a mix of family, neighbours, and friends, helping each other during the metalmaking 'season'? Given the scarcity of evidence for any hierarchical structure in the Balkan Chalcolithic communities (cf. Porčić, 2019), we may legitimately ask what the likelihood was that they were organised as a collective (for example, with everyone having equal decision-making power). As Iles (2018) has convincingly demonstrated in her ethnographically-informed study of the social landscapes of iron metallurgy in Africa, the globally influential interpretations that invariably portray African metal smelting as a secret and exclusively male activity do indeed stand up to detailed investigation. Future exploration of these nuances in both fieldwork and laboratory settings will allow us to gain more insight and reveal a more complete picture of how past smelters operated and interacted within the boundaries of their personal, social and environmental surroundings.

Fig. 12 **a** Copper-smelting experiment in Serbia in 2013 aimed at reconstructing the earliest metal extraction process based on archaeological and laboratory reconstructions. Note 6 blowers, one drummer and one master smelter (upper left), with two people in the back waiting as a replacement for the blowers; **b** Ideal reconstruction of the hole-in-the-ground smelting installation from the site of Belovode in Serbia (photo CC BY-NC-ND 4.0 J. Pendić and M. Djurica @Reuters)

One key question that arises from the experimental work is why do we do not see the inferred hole-in-the-ground ‘furnaces’ in the field, other than through indirect evidence such as slagged pre-fragmented lining sherds (Fig. 4c–d). However, as we see from Fig. 13, these structures are hardly recognisable a mere nine months after the smelting event (assuming that the ‘furnace’ is used only once; this may of course not have normally been the case). Thus these structures are ephemeral due to the very rapid nature of their construction: in our experimental case it took a maximum of 30 min to dig a shallow hole and line it with sherds, using clay as a binder. We can infer that such smelting installations were not intended to be durable, but rather to be ready for operation in a relatively short time wherever needed. As such,

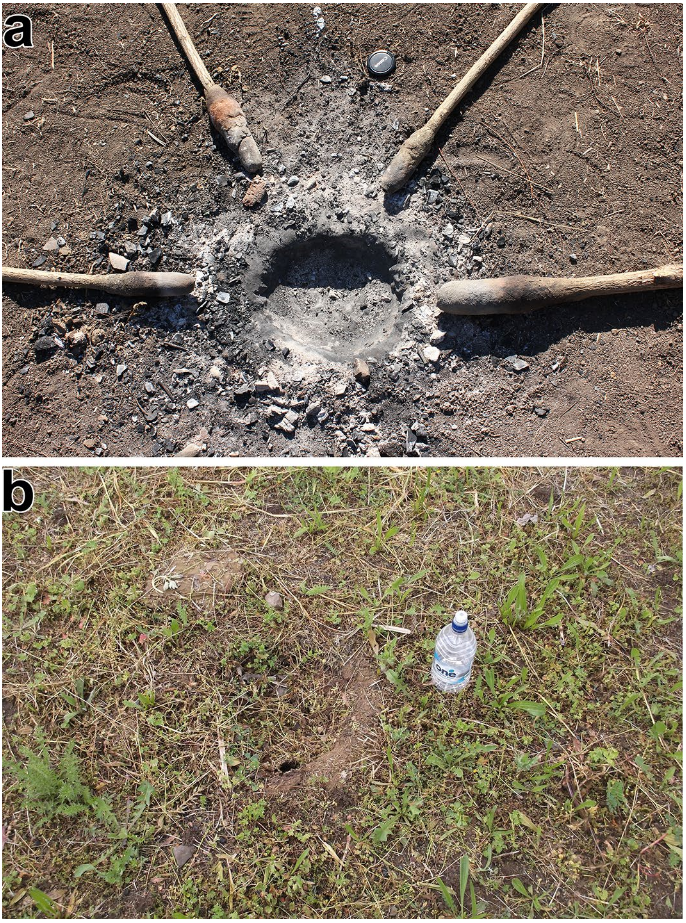

Fig. 13 **a** Installation from Fig. 12b post-smelting; **b** Installation from Fig. 12b after 9 months (photo CC BY-NC-ND 4.0 J. Pendić and M. Radivojević)

they could have been built anywhere on or off the settlement site, the only evidence of their existence left for subsequent archaeologists being the ores, slags, slagged sherds and potentially metal artefacts.

This brings us to the question of how many smelting installations or 'workshop areas' we can estimate based on the current evidence. In the case of Belovode or Pločnik, both of which we studied in detail and excavated, it seems very likely that that every household produced some metal in its back yard or communal area. This is corroborated by the extensive evidence for hundreds of copper ores found in every context and every feature, including every dwelling and every communal area across both sites (Radivojević et al. in press; Šljivar 1993–2009; Šljivar and Kuzmanović-Cvetković 1996–2009). The ores present were predominantly manganese-rich, black-and-green copper ores, which we know were used for copper extraction (cf. Radivojević, 2015). Slag and slagged sherd finds are notoriously rare at both sites (and beyond); however, an excavation recovery bias must be taken into account, as slag is essentially dark grey or brown, and small, crushed samples are very hard to discern in the soil. It is salutary to note that the small (less than one gram per sample) copper slags at Belovode were only identified in the field because they included some remaining copper metal with green patination, otherwise they would have remained invisible to the excavator (Radivojević et al. 2010b, p. 2779). These finds were held for 14 years at the National Museum in Belgrade in a box mislabelled 'copper minerals', because, at the time, nothing was known about the copper smelting in the Vinča culture save for how these early slags might have appeared. This experience highlights the need to include magnets (to detect Fe-rich slag matrix) and sieving as regular practice in future excavations targeting Chalcolithic sites in the region and beyond, otherwise evidence for early metallurgy could easily be missed.

The widespread presence of copper ores at Belovode and Pločnik calls for a different interpretation of metallurgical activities at these sites, with implications for other sites with similar evidence. We would argue that the pursuit by archaeologists of an early metallurgical specialist workshop operated by an individual smith reflect a romanticised—even mythological—ideal that may well resonate in Childean narratives but is simply not reflected in the reality of the archaeological and archaeometallurgical evidence. A very different perspective emerges with high-resolution fieldwork integrated with laboratory analyses and experimental reconstructions. This new interpretative framework comprises:

1. Multiple production episodes due to the limited scope for mass production using the hole-in-the-ground furnaces;
2. Then, implied by (1), collective and co-ordinated actions by groups of people, from the acquisition of the ore through to the production stages;
3. Community-wide access to the knowledge and practices of metal production;
4. No evidence for individual specialist smiths, operating independently.

On this last point, there is a lack of differentiation in the general material culture assemblage in the excavated dwelling features. In addition, even at the Varna 1 cemetery, Leusch et al. (2017) argue convincingly that there are considerable challenges to any confident identification and interpretation of a given grave as specifically belonging to a metalworker, whether through the associated artefacts or by osteological analyses. In further support of this notion, papers in Brysbaert and Gorgues (2017) demonstrate that establishing the societal identity of specialist craftspeople in European prehistory through the evidence of their crafting activity is highly complex, and show that analogy with ethnographic case studies from other continents or myths from other societies emphasising the separation and relative status of the smith (including gender) may be more problematic than previously thought (cf. Budd & Taylor, 1995).

Returning to Varna and the pursuit of markers for individual wealth, the most common example cited is the individual in burial No. 43. Yet, this burial is one of three skeletal graves in the assemblage of the 11 richest (known as Group A), the other eight being symbolic graves or cenotaphs (Leusch et al. 2017, p. 112, table 2). An interpretation of the symbolic graves suggests that wealth may have been deposited as an expression of 'collective social identity', and as such does not reinforce the social order so much as strengthen their ties with the dead (Biehl & Marciniak, 2000, p. 202). This is supported by the fact that none of the deposited items were used (some were even crudely made), and there is no evidence from the settlement research to show hierarchy or any form of strong social differentiation akin to that assumed in the cemetery (Ivanova, 2007; Leusch et al. 2017, p. 113). By highlighting that the Varna cemetery was the end product of a dynamic process that mobilised all available resources to define and display the community's identity, Biehl and Marciniak (2000) approach the point that we are making here about the cooperative nature of metallurgical production in the Chalcolithic Balkans.

In further support of the notion that investment in craft production may have been prompted by demand for ceremonial communal activities, Spielmann (2002) illustrates ethnographically that economic intensification and even craft specialisation can evolve to meet an increased demand for the food, exchangeable items and paraphernalia required for effective participation in collective ceremonial events. In an extensive review of social complexity and inequality in the Chalcolithic Balkans, Porčić (2019) notes that trends in the development of copper metallurgy and other crafts, the circulation and production of items of exotic raw materials, household size, cattle husbandry and population size increase in the 5th millennium BC in comparison to the previous period. However, they remain at levels too low to allow them to be seen as marking the rise of inequality. Porčić builds on this, arguing that the presence of craftspeople is not sufficient grounds for claiming the existence of an elite that supported them, or that the economy at the time was directed from a single centre. Rather, the incentive for craft specialisation (in our case metallurgy) came from a sociopolitical arena, and as such might, for example, have developed to supply the need of all participants in ceremonial events that involved metal tools.

There is, however, a notable increase in wealth during the 5th millennium BC in the Balkans. Orton (2010, 2016) indicates a general increase in the number of cattle bones in faunal assemblages, which may have been partially due to investment in the social arena, with cattle representing a form of wealth (cf. Russell, 1998). Moreover, the difference in wealth can be seen in the presence of status markers such as the macehead (*sensu* Siklósi, 2005) from Divostin II. This was found in House 13, which also differs in size and assemblage from other excavated houses at the site (Porčić, 2009, 2012a). The same applies to the presence of large houses and households in settlements like Divostin and Stubline, which Tripković (2009) argued reflect extended or multi-family households. The creation of larger basal units (such as households) and many levels of decision making is at the core of Porčić's (2019) argument that Vinča society was most probably organised as a sequential hierarchy (*sensu* Johnson, 1982), or with decisions made by consensus within a household group before a representative is mandated to negotiate at village level. This kind of organisation enabled a relatively egalitarian decision-making process. In this context, the interpretation of large buildings with house floor areas of 100–200 m^2 is of great significance. As there is no evidence to suggest that such buildings were either homes for a local elite, or temples (Chapman, 2010), they can perhaps be seen as communal buildings that enabled the working of sequential hierarchies, as their size would be appropriate for the relatively low level of integrative function needed (Porčić, 2019).

In the absence of any indication of centralised decision making or elites, or even the presence of noticeable differences in wealth, it is safest to assume that the wealth we can identify belonged to a household unit, or groups of households representing an extended family, a clan or indeed a cooperative community. An interesting find from the Vinča culture site of Stubline potentially sheds a novel light on this perspective. Forty-three clay figurines were recovered, together with 11 miniature clay models of (copper) implements in seven or eight spatial clusters (Crnobrnja, 2011; Crnobrnja et al. 2010). These figurines were found arranged (Fig. 14) in front of a large domed oven inside a dwelling structure, surrounded by ceramic material typologically characteristic for the Vinča D2 phase, and dated to c. 4650/4600 BC (Crnobrnja, 2011, p. 132). Forty-two of the figurines are identical in their design, having carelessly-shaped cylindrical bodies with bird-like heads. They contrast with the remaining figurine, a much larger object that was made with more technical skill. All the figurines have a hole in the right shoulder, and in some of these the miniature model tools seem to have been inserted (possibly using an organic material for handles). Unlike the figurines, the clay models of the implements were meticulously shaped and polished, with particular attention paid to fine details. Their form even allows for the distinguishing of different types of tools, such as hammer-axes, pickaxes, long tools with a blade, mallets and a macehead or 'sceptre' (Crnobrnja, 2011, p. 134). Interestingly, some of the miniature implement models in clay are strikingly similar to their contemporaneous full-size counterparts in copper metal. One looks like the gilded hammer-axe from Varna 1 (burial no. 4) and others look like the Pločnik hammer-axes, while a counterpart for the macehead or 'sceptre' can be found at Divostin II (House 13) (Leusch et al. 2017, p. 113, fig. 7; Porčić, 2019). Not all the figurines have clay tools associated with them, but all have a hole in the right shoulder, implying that possibly these suffered from post-depositional

Fig. 14 A selection of the Vinča culture figurines from the site of Stubline. The central figure has a clay model of a sceptre; others have clay models of hammer-axes (after Crnobrnja, 2011, pp. 140, fig. 9 copyright A. Crnobrnja)

processes. While the figurines at Stubline are undoubtedly important, exactly what they represent has been a matter of debate. While the tall figurine with a macehead (a status marker) may be interpreted as anything from a representation of a highly-ranked individual to a deity, the presentation of an equal community with carefully and distinctively designed miner's and metallurgist's tools may represent one of our 'cooperatives', as seen through the eyes of the artisan at the time. If the possession of copper was considered an indication of prestige or wealth, then the Stubline figurines may well show that it was equally distributed within a practising community.

At a broader spatial and temporal scale, we can gain clearer insights into the relationships between metallurgy and metallurgists and their communal organisation across the Balkans, not through the vague postulation of some 'metal-using elite' but rather by exploring how metal relates to broader demographic patterns, settlement densities and community interconnections. Recent research has revealed that there is a clear increase in the number of settlements during the Balkan Chalcolithic (Porčić, 2019) and, by extension, an increase in population densities at settlement sites (Rosenstock et al. 2016). These two trends would have significantly enhanced any production activities that required communal activity and cooperation. When integrated with the evidence from network analyses, which suggests that communities were frequently and regularly cooperating in the production and distribution of metal artefacts (cf. Radivojević & Grujić, 2018), it is clear that the societies in the Balkans provided an institutional and technological context within which metallurgy was able to thrive. However, there is no evidence to suggest that metal played a causal role, either in creating a larger population and denser settlement in the region, or in the emergence of the interconnections spanning the many communities, as these trends can be seen to emerge in the 6th millennium BC (Porčić, 2019). The influence of metallurgy and metallurgists on a diversity of partially overlapping and fluctuating communities across the Balkans may have been felt most in the further development of pre-existing connections, as well as in the emergence of some new areas of cooperation and connection within and between communities. It is only when (as here) metals are compared to other widely distributed materials and technologies that both pre-date and are contemporary with metallurgy—such as obsidian and graphite-painted pottery—that their role can be more thoroughly evaluated. Our evidence makes it increasingly problematic to argue that metal defined the organisation of these communities.

Early Metallurgy and Society in the Balkans and Beyond

Narratives about the emergence and evolution of Balkan metallurgy have always been modelled on developments in the Near East (or, more precisely, Southwest Asia) following a very well-worn trend in scholarship from the late nineteenth century onwards that identified *Ex Oriente Lux* or 'light from the east' to explain the emergence of 'European civilisation', as argued influentially by Montelius (1899) and Childe (1930). This paradigm has proved immensely durable over the last century in debates about the presence and transmission of specific innovations—from agriculture to urbanism—both in and into the Balkans and the west from the mid 7th to the mid 1st millennium BC. The transmission of farming technologies and practices, plants, and animals, as well as new pyrotechnologies such as ceramics from the Near East to Anatolia and onwards to the Balkans in the mid 7th millennium BC is, indeed, very well evidenced and clearly established by both past and more recent scholarship (see de Groot, 2019; Ivanova, 2020; Shennan, 2018; Whittle, 2018). This earlier confirmation of the *Ex Oriente Lux* model has consistently created a strong intellectual momentum for believing in a Southwest Asian origin for metallurgy that only a few individuals such as Renfrew (1969), Jovanović (1971), Ottaway (Jovanović & Ottaway, 1976) and Todorova (1978) have challenged by arguing instead for the independent origins of Balkan metallurgy. The resumption of the Belovode and Pločnik excavations as part of a clear agenda by Kuzmanović-Cvetković and Šljivar (1998) to demystify the Vinča metallurgy debate met with scholarly resistance at the time. The subsequent work of the first author, who joined these excavations as a student (Radivojević et al. 2010b), led to the interdisciplinary research project *The Rise of Metallurgy in Eurasia: Evolution, Organisation and Consumption of Early Metal in the Balkans*, data, analysis and interpretations from which are currently in press (Radivojević et al. in press).

We now see that across Europe and Asia the introduction of different metals and technologies differs across the three 'heartlands' of metallurgy—the Balkans, Anatolia and Iran—in the 5th and 4th millennium BC. For instance, in the Balkans, the polymetallic 'revolution' occurs around the mid 5th millennium BC, when after c. 500 years of making only copper (and possibly lead), we see gold, tin bronze and (probably) silver being produced before the end of the millennium. In Iran, early metal follows a similar pattern to the Balkans (copper and some lead). However, despite evidence for the silvery alloy CuAs from the early 5th millennium BC, true polymetallism occurs in Iran towards the end of the 5th millennium BC and beginning of the 4th millennium BC with a complex range of copper alloys, gold and silver; tin bronzes do not appear before the end of the 4th millennium BC. For Anatolia, native and/or smelted copper is the primary choice until the mid 4th millennium BC, when silver-like alloys first emerge (CuAs, CuAg), followed by tin bronze at the same time as in Iran (data from Helwing 2013; Lehner & Yener, 2014; Leusch et al. 2015; Radivojević & Roberts, 2013; Radivojević et al. 2013a, b; Roberts et al. 2009; Thornton, 2001, 2007, 2009, 2010). The fundamental conclusion that emerges from these comparisons is that there is no single narrative for metal technology that unites these neighbouring regions into a single entity in either the 5th or the 4th millennium BC.

When placed against the broader picture, this highlights the need for metal to be de-coupled from debates concerning social inequality. The period of the 5th–4th millennium BC in the Balkans and Southwest Asia is especially important in this respect, as successive generations of scholars have argued that there are no great differences between these regions in terms of demographic, material, or environmental perspectives, and thus no great differences in their potential to develop urbanism and civilisation in the 5th millennium BC (Porčić, 2019; Tringham, 1992, pp. 133–134). However, the 4th millennium BC in the Near East yields what Graeber and Wengrow (2021) have robustly characterised as the elusive evidence for territorial attachments that lead to private ownership, and then to a surplus of food, which in turn leads to the accumulation of wealth and power beyond the immediate kin-group, and ultimately to the production of sophisticated weapons, tools, vehicles, and the rise of cities and centralised governments (and women in harems), with bureaucrats and priests making sure that the imbalance is maintained, but nevertheless with writing systems whereby a single ‘correct’ version of the past could be recorded. All this is seen as in complete contrast to the dispersed farming communities of the Balkans, where the negative perception is created of a peripheral region that missed its opportunity to become ‘civilised’.

The data shows that the 5th millennium BC Balkan communities did not ‘run headlong for their chains’ (*sensu* Rousseau, 1761), or put simply, the early advances made in polymetallurgical technologies did not result in the emergence of cities and states. It seems clear that one of the major reasons why the concept of an independent origin for Balkan metallurgy was for many decades considered too bold was that accepted wisdom saw the development of metallurgy (just as social evolution) as following the Southwest Asian model and therefore as deeply intertwined with the *Ex Oriente Lux* concept. Taking into account the volume, depth and analytical sophistication of archaeological and archaeometallurgical research conducted in the Balkans over the past fifty years and synthesized and commented on here, it is clear that late nineteenth century narratives connecting metallurgy and a single perception of social progress have no place in twenty-first century archaeology.

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