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The dawn and rise of antimony use in the southern Caucasus

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Abstract Antimony (Sb) was utilised over several millennia as the prime material to opacify or decolour glass and glazes, as well as an accompanying element in copper (Cu) alloys. Metallic antimony objects are rare, and mostly confined to Chalcolithic Central Italy and to the first millennia BCE in the southern Caucasus. The innovation of antimony use in metallurgy seems to be confined to the southern Caucasus, and the invention of it might be even more specifically situated in the Great Caucasus. Pre-existing knowledge of mining set the pathway for the initial stage of antimonial copper alloys in the first half of the third millennium BCE and for metallic antimony ornaments in the second half of the third millennium BCE. However, the first major expansion of antimony in the metallurgy of the Racha-Lechkumi district in the southern Caucasus (present-day Georgia) started around 1700 BCE, while its spreading in glassmaking occurred in the Late Bronze Age (LBA). Explanations that place antimony adoption within its broader social context are favoured over those that consider material or geological properties in isolation. A recurring theme is the importance of comparative analysis, both geographically and between the different pyrotechnologies, including the precious metals and glass industries, to explore how social, political, climatic and economic conditions affected adoption and innovation patterns. All these factors are considered to explain why the extraction of antimony blossomed in the Late Bronze Age in the southern Caucasus and to reconstruct a framework of exploitation, distribution/trade and use of antimony in the Caucasus and its neighbouring regions in the south and east.

Keywords Antimony, Caucasus, Metallurgy, Glass, Gold

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1. Introduction

Antimony (Sb) minerals show a long history of use, both in ancient glass making (as an opacifier and decolouriser) and in metallurgy (either as an accompanying element or as a pure metal). Antimony is found in copper alloys as well as a pure metal, though the conscious use of antimony is debated.

Antimony occurred in metallurgy, either as an accompanying element or as a pure metal, from the Chalcolithic period onwards (see Table 1). Metallic Sb ornaments appear, next to some rare occasions, consistently in two regions throughout the Old World: in Central Italy during the Chal-

colithic period, and in the southern Caucasus during the second and first millennium BCE (see Table 2). Antimony also occurred in ancient glass making as an opacifier and decolouriser from the Late Bronze Age until the Roman period. A list of attestations, dating to pre- and protohistory in the Old World is incorporated (Tables 1 and 2) with the intention of providing the most complete picture possible. However, by no means it claims to be fully comprehensive.

Despite this longevity and ubiquity in use, antimony ore extraction in prehistory has only rarely been studied (for a short introduction, see Giardino, 1998; for antimony production in medieval times and later, see Siebenschock, 1996). Questions concerning provenance, distribution of raw materials and the nature of its technological processes are

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Table 1 Overview of the attestations of antimonial copper alloys from the Chalcolithic period to the Iron Age

Period	Region	Culture/dating	Alloys	Traces	Sites	References
Chalcolithic	Anatolia	Kura Araxes culture-mid 4th millennium BCE	Cu-As-Sb-(Fe)	Ag, Ni, Pb	Arslantepe, Norşuntepe, Kül'tepe	Golden et al., 2001
	Balkan	Vinča culture, ca. 4400 BCE	Cu-As	Sb, Sn	Gornja Tuzla	Radivojević, 2015
	northern Caucasus	Maikop culture (3800–3250 BCE)	Cu-As	Ni	Maikop	Chernykh, 1992
	southern Caucasus	Sioni culture (4800/4600–4000 BCE)	Cu-As-(Ni)	Zn	Tsiteli Gorebi, Chalagan Tepe	Courcier, 2014
	Iranian plateau	Phase I (4200–3800 BCE)	Cu-As, rarely Cu-Sb	Ni	Tepe Hissar	Fleming et al., 2011; Avilova, 2008
	southern Levant	Ghassulian culture (4500–3800 Cal BCE)	Cu-As-Sb	Ag, Au, Bi, Fe, Ni, Pb, Sn, Zn	Nahal Mishmar, Pepi'in, Nahal Qanah, Bir es-Safadi, Abu Matar, Nahal Badir, Shiqmim, Giv'at Ha'oranim, Ze'elim, Palmahim	Shalev and North-over, 1993; Tadmor et al., 1995; Segal et al., 1998; Golden, 2014; Ben-Yosef et al., 2016
	Tuscany, Umbria and northern Latium (Italy)	Rinaldone culture (early to mid-4th millennium BCE)	Cu-As-Sb alloys	Ag, Bi and Ni	>1 wt% Sb: Ponte San Pietro, Garavicchio, Petignano del Pozzo, San Casciano, Montespertoli, Sgurgola, Solaia, Montalto, Castelluccio Foce, Pomarance, Monte San Savino, Ungheria, Rinaldone, Cortona, Pienza, Guardistallo, Arezzo, Pallazzone, Grosseto, Fermignano, Caramanico, Poggio Olivastro	Dolfini, 2014
	Anatolia	3500–3000 BCE	Cu-Pb-As, Cu-As-Ni alloys	Ag, Fe, Sb	Arslantepe, Norşuntepe, Polatlı and Ahlatlıbel	Yener et al., 1991; Hauptmann et al., 2002; Golden, 2014
	Cilicia (Turkey)	2700–2400 BCE	Cu-Sb alloys		Soli Höyük, Tarsus	Novák et al., 2017
	northern Caucasus	Koban culture	Cu-As-Sb, Cu-Sn, Cu-As-Sn	?	Koban, Chmi	Mödlinger and Sabatini, 2017
Bronze Age	southern Caucasus	EBA (3300–2100 BCE)	Cu-As-(Zn), Cu-Sb	Ag, Ni, Pb, S and Sb	Ozni, Kvatskhelebi, Dzagina	Chernykh, 1992
		MBA-LBA (2nd millennium BCE)	Cu-Sb-As	S	Brili, Bornighele, Treligorebi, Zagwli, Kvasatali, Itchwissi, Meskheti	Hauptmann and Gambaschidze, 2001
	China	late Shang period (ca. 14th–12th century BCE)	Cu-Sb, Cu-As-Ni, Cu-Sn, Cu-As	As, Ag, Pb	Hanzhong	Chen et al., 2009
	Hungary	MBA-LBA	(Cu)-Sb	?	Velem St. Vid	Davies, 1935
	Italy	Polada culture/EBA I (2200–2000 BCE)	Cu-(As)-(Sb), Cu-Sn	As, Sb, Ag, Ni	>1 wt% Sb: Amelia, Campiglia d'Orcia La Casetta Muriccia, Ripatrasone	De Marinis, 2006; Dolfini and Peroni R, 2010
Iron Age	Iran	Iron II/Hasanlu IV B: 800 BCE	Cu-(Sn)-Sb	Ni, S	Hasanlu	Fleming et al., 2011
	Egypt	630–300 BCE	Cu-Sn-S-Pb, Cu-Sb-Pb	As, Ag and Bi	Naukratis	Masson-Berghoff et al., 2018
	Russia	EIA (1000–300 BCE)	Cu-As in Altai region, Cu-As-Sb predominance in Lake Baikal regions	Ag	Various sites	Hsu et al., 2016

still not satisfactorily answered. As of when were antimony minerals seen as a commodity on their own? What is the primary origin of the antimony raw materials used? How was this antimony distributed, by processes of trade, exchange or tribute? What was the nature of its adoption in several technological processes? The identification of the primary origin of antimony raw materials used, both in terms of

geographical origin as well as the type of mineral used, is discussed in this paper.

Since the southern Caucasus is the area where most of the antimony-rich metal artefacts of interest have been found, and where antimony-rich minerals were specifically mined, this region merits our prime interest. In this paper (see Figure 1), the southern Caucasus (or Transcaucasia) is delineated as

Table 2 Overview of attestations of the metallic antimony objects from the Chalcolithic period to the Iron Age

Period	Region	Site	Culture/dating	Finds	Metal	References
Chalcolithicum	Turscany, Umbria and northern Latium (Italy)	Montebradoni	Rinaldone culture	Buttons with V-shaped perforations	metallic Sb	Cambi and Cremascoli, 1957
		Grotta del Fontino	Rinaldone culture	Tomb 21: bead (elongated cylindrical) + steatite		Zanini, 2002
		Ponte San Pietro	Rinaldone culture: 3635–3376 BCE (associated F skeleton)	Tomb 21: beads (elongated cylindrical)+ silver bead		Miari, 1993
		Selvicciola	Rinaldone culture: 3780–3640 BCE	T21 (E sector): bead + iron fragment, faience/frit bead	Valentinite Sb ₂ O ₃	Petitti et al., 2012
			Rinaldone culture: 3780–3640 BCE/ 3633–3373 2σ/ 3637–3377 2σ/ 3637–3375 2σ Cal BCE (not directly associated)	T23 (E sector): bead		Grazzi et al., 2012
			Rinaldone culture: 3780–3640 BCE	T35 (E sector): bead + silver bead		Grazzi et al., 2012
Bronze Age	Iraq	Tello	3000 BCE	“Chaldean vase”	metallic Sb	Moorey, 1999
		Assur	2000 BCE	jewellery		
	Syria	Tell Leilan	3rd millennium BCE	cast tube, probably bead	metallic Sb (99.7%)	
		Jerablus Tahtani	2500–2300 BCE	tube bead	metallic Sb with traces of As, Pb, Sn	Moorey, 1999 ; Shortland, 2002a
	northern Caucasus	Mamai-Koutan	Kayakent-Khorochoi culture (2nd millennium BCE)	ornament	metallic Sb	Chernykh, 1992
		Korochoi	Kayakent-Khorochoi culture (2nd millennium BCE)	Burial 2: ornament		
		Kayakent	Kayakent-Khorochoi culture (2nd millennium BCE)	Burial 16: ornament		
	southern Caucasus	Kvazchela	ca. 2500 BCE	bead	metallic Sb	Stöllner and Gambaschidze, 2011
		Lchashen	Karmir-Berd culture: 1500–1200 BCE	not specified		Meliksetian and Pernicka, 2003
		Artik	Karmir-Berd culture: 1500–1200 BCE	not specified		
		Metsamor	Karmir-Berd culture: 1500–1200 BCE	not specified		
		Redkin Lager	Karmir-Berd culture: 1500–1200 BCE	12 small objects		Lindsay and Smith, 2006
		Cheshmanis	13th–12th BCE	not specified		Tite, 2002 ; Meliksetian and Pernicka, 2003 ; Meliksetian et al., 2011
		Bjini	1500–1200 BCE?	button		Meliksetian and Pernicka, 2003 ; Meliksetian et al., 2011
		Brili	middle 2nd millennium BCE	Tomb 1: 4 buttons; Tomb 32: necklace with beads		Hauptmann and Gambaschidze, 2001
		Treli	14th–13th century BCE	Tomb 162: 8 buttons		
		Kvasatali	Trialeti culture: 16th century BCE	Tomb 8: 6 buttons; 8 buttons		
		Tsaghvli	16th–14th century BCE	Tombs 1, 7, 11 and 82 : 8 needles with Sb head, 23 sliders and 5 beads		
Iron Age	Mesopotamia	Hasanlu		four objects	Metallic Sb (96.5–99% Sb)	Fleming et al., 2011
	Egypt	Lahun	22nd dynasty (945–716 BCE)	not specified	metallic Sb	Petrie, 1891 ; Shortland, 2002b

the southern flanks of the Great Caucasus Range and the area south of this mountain range. Transcaucasia roughly corre-

sponds to the three modern independent republics of Georgia, Azerbaijan, Armenia, along with the disputed regions of



Figure 1 (Color online) An overall map of the geographic regions as mentioned in this paper (mapped in ArcGIS by the author).

Abkhazia, North-Ossetia and Nagorno-Karabakh. The land north of the Greater Caucasus is called Ciscaucasia or simply northern Caucasus (Sagona, 2017).

Previously developed antimony isotope analysis (Lobo et al., 2012, 2013) has allowed Late Bronze Age (LBA; 1600–1200 BCE) Egyptian and Mesopotamian glass vessels (Degryse et al., 2015) and Caucasian antimony metallic beads to be compared to possible ancient ore sources from across the world (Degryse et al., 2020; Dillis et al., 2019). The only known matches so far for the isotopic composition of the glass are stibnite ores from the Racha-Lechkumi district in the Caucasus (present-day Georgia) published in Dillis et al. (2019) and Degryse et al. (2020). Here, we use these data to compose a regional synthesis on the topic of the use of antimony in the southern Caucasus and to obtain a better understanding of the mining, provenance and exchange of the antimony raw materials used in the Racha-Lechkumi region, and the development of antimony use in metallurgy in the southern Caucasus as a whole. Such synthesis sheds light on the broader aspects of innovation and invention. In this paper, an invention is defined as “the initial appearance of an idea or process, whether truly novel, or a distinct modification of an existing idea or process” (Killick, 2015), while innovation is considered as “an invention that is widely adopted” (Killick, 2015). Metallic antimony ornaments appear consistently in only two regions throughout the Old

World during the first millennia BCE: in Central Italy during the Chalcolithic period (Cambi and Cremascoli, 1957; Miari, 1993; Grazzi et al., 2012; Petitti et al., 2012), and in the southern Caucasus during the second millennium BCE (Hauptmann, 2001), besides some rare occurrences during the third millennium BCE. Antimony objects dating to the third and second millennium BCE are also sporadically found in Mesopotamia and the Levant (Moorey, 1999) but were likely imported. The innovation of antimony use in metallurgy is confined to the southern Caucasus, while in Italy, there is clearly the invention of antimony use in metallurgy (Pallecchi et al., 2002; Dolfini, 2014), but this process is extinguished by the end of the Early Bronze Age (EBA) (De Marinis, 1999). We compare the origin of the mineral resources used for glassmaking with the use of antimony minerals in metallurgy to reveal possible interrelations between these industries and to determine how antimony was adopted in several technological processes.

The Childe (1944)/Snodgrass (1980) stage-based model will be applied to the appearance and dispersion of metallic antimony beads of the Racha-Lechkumi region (Dillis et al., 2019). In broad terms, this stage-based model divides any technological transition into a beginning (initial stage), middle (transitional stage, early adopters), and end (late adopters, final stage), but in doing so, often obscures underlying variability in adoption processes (Leek, 2014;

Snodgrass, 1980). Nowadays, it is clearly understood that patterns of metal usage do not always follow linear trajectories (Erb-Satullo, 2019). Nevertheless, the model is appealing for its descriptive elegance.

The first phase should not be seen as the uprising of the first antimony-rich objects, but should be regarded in the light of pre-existing knowledge; hence we will add a prequel stage as well. The second phase we subdivided into “initial stage I and II”. “Initial stage I” is when the antimonial copper alloy is produced, i.e., copper-based alloys with more than 1% Sb appear as a result of the smelters' knowledge to produce complex copper alloys, though antimony as such may remain unrecognised. The term ‘alloy’ carries many meanings and has diffusely been defined in the archaeological literature. In this paper, the term alloy is used for-citing Stech (1999)—“*when two or more metals are, intentionally or inadvertently, mixed together in the presence of heat; the product is assumed to have some kind of desirable, enhanced properties*” (Stech, 1999). Besides the fact that the aim to enhance the finished product is a deliberate choice, it remains critical to question how the alloying was done, as it sheds light on the control possible and the intentions of the crafts people. A wide range of antimony in these alloys is noted in this paper (1% up to 20% and more; see Table 1), that probably reflects different technological practices and hence different degrees of intentionality over time and per region. A more rigorous (statistical) comparison of these antimonial copper alloy assemblages is needed in order to demonstrate intentional alloying in an assemblage (cf. Pollard et al., 2019). “Initial stage II” is when this knowledge results in the first and rare occurrences of metallic antimony beads. The “early adoption stage” is when antimonial copper alloys are predominantly used, but metallic antimony objects are less frequently encountered. The “late adoption stage” is when antimony as a raw material is used intensively for the production of both complex copper alloys, metallic antimony objects and potentially in other pyrotechnologies. This is the “Antimony Age” proper. Finally, we conclude with the decline of antimony use, referred to as “the aftermath”. This chronological framework is graphically represented in Figure 2.

2. The prequel

There are persuasive geological, archaeological and technological arguments to support the claim of a local metallurgy, focusing on precious metals prior to antimony metallurgy in the Caucasus. On geological grounds, the Caucasian region is one of the most important ore-bearing regions in the world. Copper is the most commonly occurring metal, but gold is well represented too, both as primary and placer deposits. The presence of tin, in the form of

cassiterite and stannite deposits, located along the central region of the Greater Caucasus (e.g., Bzhuzhi and Vakijvari gorges) is particularly noteworthy, given that the region is characterised by tin bronzes early on in the stages of metallurgy (Erb-Satullo et al., 2015). According to Greek mythology and historical sources, the ancient Georgian Kingdom of Colchis was rich in “gold sands”, and the natives took this metal from the rivers. The Svans (present-day Georgia) are still mining gold from these mountain rivers as they presumably did in ancient times, using sheepskin, and special wooden vessels of ash-tree. The fleece with the captured gold grains is taken off the water and gold is washed out of the skin before further processing. The “Golden Fleece” is, in that case, a symbol for the recovery of gold from placer deposits. The “gold sands” mentioned in ancient Greek mythology and in historical sources are thus a geological reality and the gold content in the river sands of this region is sufficiently high to give grounds to the legends that describe Svaneti as the “country rich of this precious metal” (Okrostsvavidze et al., 2016; Hauptmann, 2011).

Archaeologically speaking, it is interesting to note that nowhere else in the EBA world of the second half of the fourth millennium BCE such a large number of exquisite gold and silver items has come to light as in the northern Caucasus. Such archaeological finds are mainly illustrated by the treasures of the Maikop and Staromyshevtovskaja kurgans (barrow burials) (Courcier, 2014). The number of precious metal artefacts found in the largest Maikop kurgan is extraordinary: a total of no less than 2 kg of gold and 3 kg of silver were deposited in the tomb. More precious metal artefacts were also discovered in other kurgans linked to the Maikop phase (Sagona, 2017). In contrast to the northern Caucasus, gold and silver objects are rather rare (Sioni group and Kura-Araxes culture) in the southern Caucasus during the fourth millennium BCE. An earring with a weight of 9.4 g of gold/silver has been found at Paravani Kurgan N1 and the gold and silver jewellery of Soyuk Bulaq are another rare example (Stöllner et al., 2014).

The rise of systematic mining in the Caucasus at the end of the Chalcolithic period, not restricted to metal ore mining but including salt mining as well, proves pre-existing knowledge of mining techniques (Courcier et al., 2017) which may have facilitated the start of antimony metallurgy later in time. In the exceptional prehistoric salt mine of Duzdağı (Nakhchivan, Azerbaijan), located near the Aras River, mining operations were carried out from the Chalcolithic period, possibly from the second half of the fifth millennium BCE onwards (Hamon, 2016). Moreover, as early as this, significant metallurgical activities were being carried out at Ovçular Tepesi (Azerbaijan) (Gailhard et al., 2017).

Further archaeological evidence of the emergence of mining in the southern Caucasus dates to the second half of the fourth millennium BCE at the gold mine of Sakdrisi. It is

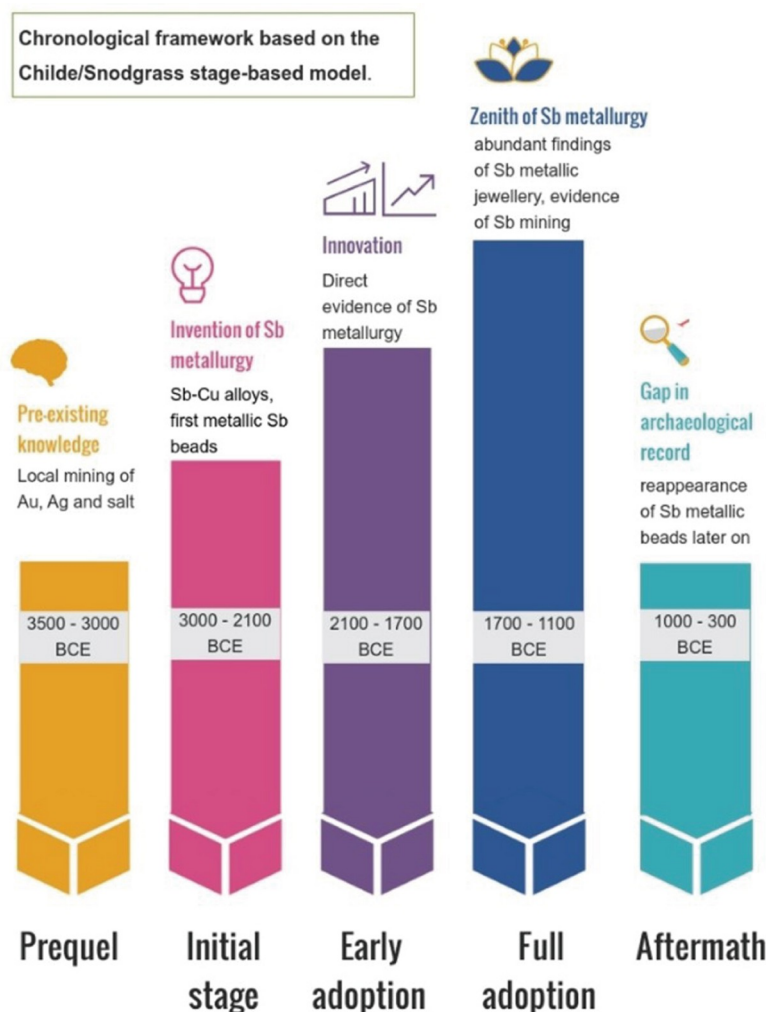


Figure 2 (Color online) Graphic representation of the chronological framework that is worked out in this article, based on the Childe/Snodgrass stage-based model.

unknown whether the ores were mined as resources intended for local consumption or for distribution throughout the Near East, or even to the northern Caucasus. In the wider surrounding of the Sakdrisi gold mine, only a few precious metal artefacts were found, of which the gold and silver jewellery of Soyuq Bulaq in west Azerbaijan are the earliest, dated to the early fourth millennium BCE. Here 33 beads of silver, 2 silver rings and 23 beads of gold were found. Also, an arsenical copper alloy with antimony and nickel traces was attested. Considering the chronology and the distance, which is only 70 km as the crow flies, it is well possible that the gold beads from Soyuq Bulaq came from the Sakdrisi mine. At Dzedzvebi (II), west of Bolnisi (Georgia), a workshop area likely linked to the Sakdrisi mine has been excavated and dated to the end of the fourth millennium BCE. Crucible fragments found at the site complete the impression that house-complexes (Kura-Araxes stage II) once formed part of a workshop area where ores were processed. All the evidence related to metal working is scattered across the settlement in different houses, in outdoor and in-

door spaces, which suggests daily metallurgical practices rather than specialised work. These activities are contemporary with the mining at the Sakdrisi-Kachagiani mine and the mineral and chemical associations of the samples taken at the site are identical with the mineral and chemical association of the deposits from Sakdrisi (Stöllner et al., 2014). This evidence clarifies the relationship between settlements and mines, as complementary with other production activities. This can be regarded as “opportunity mining”, where mining is combined with other production activities (Gailhard, 2015; Gailhard et al., 2017). There is also an example from a metallurgical workshop with a furnace, a supply of charcoal, a fragment of a tuyère, and mould at Amiranis-Gora (Georgia). Its exact dating is open to discussion, but there is a general consensus that it must have been used during the fourth millennium BCE with an earliest carbon date of 3790–3373 cal BCE. It was obtained from the charcoal of the metallurgical workshop which belonged to the earliest building horizon of Amiranis Gora (Gailhard, 2015). This indicates a similar division of the metallurgical

production into the extractive (mining) and processing branches as was seen between Dziedzvebi (II) and the mine of Sakdrisi.

The flat-axe stone-moulds, coming from a Kura-Araxes context at Chisanaant-Gora (Georgia) and dating to the second half of the fourth millennium BCE, are the earliest technological examples of the simple casting method used in the region (Gailhard et al., 2017). Moreover, on technological grounds, it is interesting to note that the EBA golden and silver figurines of the Maikop culture were produced by the technique of lost-wax casting. This observation is interesting in light of the southern Levantine antimonial copper alloys. Given the present state of research, despite the early date of the EBA figurines of the Maikop culture, the “prestigious” items from the Nahal Mishmar cave still represent the earliest known evidence for the application of the lost-wax process. Remarkably, the chemical signature of these elaborate prestige objects doesn’t match with the local ores (Golden et al., 2001; Goren, 2014). Therefore, ores, ingots or finished products had to be imported from either eastern Anatolia or the Caucasus, or both regions.

The prequel stage can, as such, be dated from the second half of the fourth to the beginning of the third millennium BCE.

3. Initial stage

3.1 Initial Stage I: appearance of antimonial Cu alloys

At the beginning of the third millennium BCE metalwork (copper, gold, silver) emerged as a separate craft branch in the Kura-Araxes culture. In contrast to the previous (e.g., Sioni culture) and next periods, most metalwork from the Kura-Araxes time is obtained from domestic contexts (cf. Dziedzvebi), hinting that metalwork entered the daily life-style. Antimony appears in the copper alloys, e.g., an awl from Ozni containing 2.7 wt% Sb, a curl-ring from Kvatskhelebi B with 5 wt% Sb and also the materials of Dzaghina have a high antimony content. By 3000 BCE the Kura-Araxes culture began to spread into eastern and central Anatolia and eventually into the northern Levant (Courcier, 2014). It occupied a vast area, i.e., north of the Taurus Mountains, stretching from the Euphrates River to North-western Iran, covering the Armenian Highland, the Caucasus and Anatolia, reaching the Levant and west central Zagros Mountains (Meliksetian and Pernicka, 2003). This spread is documented by the diffusion of the diagnostic red-black-brown burnished ceramics, which got spread as far as Palestine during the EBA II-III (Courcier, 2014).

The appearance of the first antimonial copper alloys goes hand in hand with the first attestations of silver and gold in the southern Caucasus. At Velikent (Dagestan), a gold leaf and silver rings were found in Tomb 11 on Mound III, while

a gold ringlet was discovered in Tomb 1 on Mound IV, both dated to the first half of the third millennium BCE (Courcier, 2014). More southern Caucasian attestations of metallic silver are also dated to the first half of the third millennium BCE, belonging to the Martkopi-Bedeni and the Kura-Araxes cultures. In Georgia, silver daggers were discovered at Martkopi and three silver rings have been found in the cemetery of Amiranis-Gora, while a silver bracelet and hair pendant were revealed at Hasansu in Azerbaijan. Another silver earring comes from a tomb in Kachbulag and Tombs 2 and 5 of Kvatskhelebi contained some silver spiralled rods (Courcier, 2014). With the silver, the question certainly arises if native silver was used or if it was cupellated from rich polymetallic ores. Considering that the silver spiral from Amiranis-Gora contained lead in minor amounts (quantity unknown to the author because these data are unpublished) and that also a lead spiral was found at the site (Makharadze, 2014), it would be logical to assume that the cupellation technique was used. However, no litharge has been found yet in Georgia from the fourth nor third millennium BCE (Makharadze, 2014). Few gold objects are found at the sites of Sachkhere, Dzaghina and Tvlepias-Tsqharo (Gambashidze et al., 2010).

Somewhat later are the findings of a golden earring from a tomb in Kachbulag, while a gold bead has been discovered in a house at the settlement of Mingechaur (Kushnareva, 1997). Two golden spiral-earrings were also found at Hasansu (western Azerbaijan), dated to the mid-third millennium BCE. Their chemical signature is very similar to the primary gold from the ancient mine of Sakdrisi (Stöllner et al., 2014). Since there is a chronological overlap between the kurgans of Hasansu with the younger phases of the gold mining in Sakdrisi, and since it is the only rock-gold mine so far known within a reasonable travel distance (less than 100 km), it is likely that the gold of the Hasansu earrings was derived from the gold deposit of Sakdrisi. Mineralisations comparable to Sakdrisi, like Madneuli, Sotk, Kapan, Alaverdi, and Mehmana (Armenia), are an alternative option for the gold’s provenance. It shows the possibility of the deposit being used since the lead isotopic data carried out on the Hasansu copper objects are mainly consistent with ores from the Madneuli deposit. However, despite the investigations in the region, rock-gold mining of that period has not been detected in any of these deposits so far (Stöllner et al., 2014).

For this time period, an increase in the amount of metal objects found and in the variation of the different kinds of alloys present is observed as well. The “rich” tomb of a socially significant woman at Kvatskhela (N2) is a very good example of a high variety in metal-alloys, next to precious metals. The diadem, bracelets and some beads found, consist of arsenical copper of which a number of beads show levels up to 25% As. Ornaments are characterised by copper alloys with traces of antimony and lead, while an awl had only

bismuth as trace element. Another example derives from the Armenian Kura-Araxes settlement of Gegharot where a necklace and pendants have been found, all consisting of high arsenical copper alloys of which the bag-shaped pendants had even high contents in lead (Makharadze, 2014).

The discovery of furnaces, crucibles, ingots or slags on Kura-Araxes settlements in Georgia, Azerbaijan and Armenia—all probably dated to ca. 3000 BCE—, as well as in later third millennium BCE sites such as Ispani, Shortepe, Shengavit, Igdir, Pichori, Garni (Courcier et al., 2017) and Kültepe (Schachner, 2001), firmly establish the importance of metallurgy in the Kura-Araxes culture.

Based on this framework, it seems likely that cross-craft interactions occurred, or even that precious metallurgy and antimonial copper-based metallurgy intertwined. In the metal record of the third millennium BCE, it is striking that most of the metal in graves had a symbolic rather than a utilitarian function. A potential push mechanism in this cross-craft interaction/intertwined metalworking could thus have been demand by consumers based on perceptive characteristics.

It has been suggested before that the demand for a specific colour could have been the driving force of this rather than the advantageous material properties in the production of alloys such as brass, gunmetal and As-Sb-Cu alloys (Thornton, 2007; Shortland, 2008; Fleming et al., 2011; Radivojević et al., 2013). It is striking that arsenical copper alloys and metallic silver objects appear simultaneously in the archaeological record of the Caucasus. This arsenical copper alloy has a shiny greyish, silvery colour, and it is quite likely that it was originally intended to imitate silver.

Likewise, antimony might have been used to imitate gold (Degryse et al., 2020). An amount of 1–3% Sb in copper leads to a red to brownish orange, or a dull golden colour, a content of 3 to 7% Sb gives an orange-brown golden colour with sometimes a purple hue undertone. Amounts of more than 7% Sb makes for a blue white or white silver object (Mödlinger et al., 2017). It needs to be noted that higher contents were previously mentioned by Pike et al. (1996): 10% Sb for a golden colour, 20% for a silver colour.

The golden and silvery colour may have driven the production of arsenical and antimonial copper alloys, as well as of metallic antimony beads, in order to imitate precious materials. The perceptive characteristic of colour of the final product could have been a key feature in their demand, particularly since arsenical and antimonial copper alloys developed in parallel with the rise of gold and silver production in the Caucasus. As previously discussed, in the southern Caucasus the widespread appearance of gold objects and antimonial copper alloys are dated from the beginning of the third millennium onwards, whereas the first metallic antimony bead is dated to the mid-third millennium. One can wonder whether one of these precious metals and/or alloys was perceived as the most valuable, and if so, whether

this value system changed over time.

3.2 Initial Stage II: appearance of antimony metallic beads

The use of precious metals in graves, such as those of Kvazchela N2, Hasansu or Sachkhere from the beginning of the third millennium BCE, fully developed into a funeral tradition in the Martkopi-Bedeni kurgans. A new cultural horizon, around the approximate start of the EBA III in the southern Caucasus, emerges and is characterised by the use of kurgans. This Early Barrow Culture (EBA III–Middle Bronze Age (MBA) I; 2500–2000 BCE) comprises chronologically overlapping phases, such as the Martkopi, Bedeni and Sachkhere traditions (Kvavadze et al., 2015).

The sudden rise of gold, silver and high arsenical copper alloy during the prequel stage is now expanded by another regional specialty: antimony beads. Metallic antimony beads have been found in the previously mentioned grave of Kvazchela (Stöllner and Gambaschidze, 2011), placing the first usage of metallic Antimony beads to the middle of the third millennium BCE. Still, metallic antimony beads remained exceptional during this time period. This period is also characterised by the appearance of antimonial copper alloys with 1–20% Sb and sometimes with a similarly high arsenic content (Hauptmann, 2001; Hauptmann and Gambaschidze, 2001). They are mainly assigned to the cultures of Bedeni (2500–2200 BCE) and Sachkhere (2600–2000 BCE) (Chernykh, 1992) and are characterised by traces of sulphur (Pike, 2002). In this aspect they differ from the Chalcolithic Levantine and Italian antimony-rich alloys. The following third millennium BCE examples indicate that the exploitation of antimony-rich mines potentially already occurred by the late period Kura-Araxes communities and definitely by the Early Barrow communities. Firstly, Fioletovo in the Margahovit mining district is known for yielding evidence of extraction and enrichment of copper in the EBA. Dozens of 1–10 m large open pits, holes, two sloped galleries and associated burrows were investigated. Associated archaeological material is typologically dated to the final stage of the Kura-Araxes culture (26th–22nd century BCE). The ores were mined on the slopes and taken downhill to the settlement (Meliksetian et al., 2011; Meliksetian and Pernicka, 2003). Besides, Fioletovo is a gold deposit, and prehistoric alluvial gold mining is reported in the area (Wolf et al., 2013). Secondly, based on a Sachkhere-type axe found at one of the copper ore workings near the MBA burial ground of Brili, it is suggested that the exploitation of the deposits in the area of Ghebi began during this time (see Figure 3) (Chernykh, 1992). Thirdly, settlements are noted even in remote areas and at heights of more than 2000 m. Their occurrence could be related to copper and antimony deposits there.

Outside of the southern Caucasus, at Tell Leilan (Syria), a

metallic antimony object dating to the third millennium BCE was found (Moorey, 1999). Only about 50 km to the east, at Tell Mozan/Urkesh (Syria), red-and-black burnished sherds occur in mid- and late-third millennium levels of the palace and temple, roughly concurrent with the obsidian originating from six different Eastern Anatolian sources (Frahm et al., 2016; Frahm and Feinberg, 2013). Close-by, at Jerablus Tahtani, the metallic antimony tube bead dates to 2500–2300 BCE (Shortland, 2002a). Further away, at Tello (Iraq) a metallic antimony vase has been found (Moorey, 1999). Obsidian and antimony, both either as a raw material or finished tools, likely spread through the region via similar routes as the material culture (e.g., the red and black burnished ware) (Frahm et al., 2016).

This initial phase of antimony metallurgy goes together with the onset of gold production in the southern Caucasus. Previously, gold was most likely already mined at e.g., Sakdrisi but the attestations of gold objects are limited to the northern Caucasus at first, which we defined as the prequel stage, and appear slowly from the first half of the third millennium BCE onwards in the southern Caucasus during the initial stage I. In this stage II, many gold objects such as finger rings, hair rings, spiral rings, beads, diadems, and pendants appear at sites of the Martkopi and Bedeni cultures during the EBA–MBA transitional period: Shengavit (Armenia), Stepanakert (Azerbaijan), Khachenaget (Azerbaijan), and many Georgian sites (Anaga, Ananauri, Martkopi, Bedeni, Tsnori, Paravani, Irganchai and Enamta) (Bobokhyan et al., 2017). Gold objects were mostly found together with other ornaments made of silver, carnelian, bronze and frit (Abramischvili and Abramischvili, 1995).

The exquisite gold necklace from Barrow 2 at Ananauri, dating to the ca. mid-third millennium BCE, testifies the early use of the filigree technique in the Martkopi tradition, while the gold lion found in Kurgan 12 at Tsnori shows the application of both the filigree and granulation technique in the Bedeni tradition (Sagona, 2017). These two objects are very original and suggest local manufacture (Chernykh, 1992). More recently, in 2012, another kurgan was discovered at Ananauri (nr. 3) and radiocarbon dated to ca. 2400 cal BCE. Besides other grave goods, not less than 23 items made out of gold were found (Makharadze, 2014).

The initial phase I can be assigned to the first half of the third millennium BCE in the region, and stage II to the second half of the third millennium BCE.

To date, the first antimony beads in the Old World—apart from the Chalcolithic Tuscan attestations—are found in Kvazchela dating to the mid-third millennium BCE (Stöllner and Gambaschidze, 2011). The rare finds of metallic beads further south of the region (Tell Leilan; Tello), also dating to the third millennium BCE, might reflect some other push mechanisms. First of all, the appearance of the Kura-Araxes into southeastern Anatolia and northern Syria is commonly

cited as one of the best documented and studied cases of prehistoric migration, pulled by the economic activities of these people: pastoral nomadism and trade in metals. It should be noted, however, that this pastoral element of the Kura-Araxes, albeit an important component, has been overemphasised at the expense of the agricultural element of this society. It is suggested that they were moving into ecological niches suited culturally or technologically to their existing economic activities, in which viticulture (i.e., the growing of grapes), presumably for viniculture (i.e., wine production) might have played a major role (Batiuk, 2013). It is a reasonable argument considering the earliest biomolecular archaeological evidence for grape wine and viniculture (the cultivation of grapes, especially those used to produce wine) is currently dated to ca. 6000–5800 BCE in Georgia (McGovern et al., 2017). The increasing value ascribed to wine, and the persistence of this economic subsistence system as a specialisation of the migrant communities, allowed them to maintain their cultural identity among the growing elites in the region. The few finds of metallic antimony beads during the early and mid-third millennium BCE might then simply be seen as goods taken along by the people moving from the Caucasian region more southwards.

The development of the more powerful supra-regional Akkadian Empire of Mesopotamia (2300–2200 BCE), which is also reflected in the re-emergence of more monolithic ceramic assemblages and the decline of cultural unification of the region (Batiuk, 2013), can explain why metallic antimony beads are not attested between 2300 and 2000 BCE in the Near East.

All of these pull and push mechanisms might even have been triggered by the climate shift observed during the transition of EBA to MBA. Palynological, geochemical, and isotopic climate signals preserved in Lake Van sediments suggest environmental shifts in Eastern Anatolia. Lemcke and Sturm (1997) report “decreasing humidity (temperature) and a significant shift of precipitation” after 2190 BCE, and Wick et al. (2003) noted decreasing woodlands after 2100 BCE, replaced by an open landscape (triggered by climate change or by human impact?). This coincided with a shift from a more sedentary-based life to a pastoralist way of living on the Armenian Tsaghkahovit plain. Migration routes may have shifted, and if resources fell short, this might have resulted in changes in trade, territoriality, or other resource-control strategies. Not all groups would have to be affected because, as a network, shifts in the routes of only one group could affect how commodities were distributed. Consequently, the climate could have disrupted their de facto network and e.g., also affected the disappearance of four obsidian sources from Urkesh (Frahm and Feinberg, 2013). This can be an additional explanation to why—outside the Caucasian region—a chronological gap between the “earlier” metallic antimony objects (i.e., third millennium BCE)

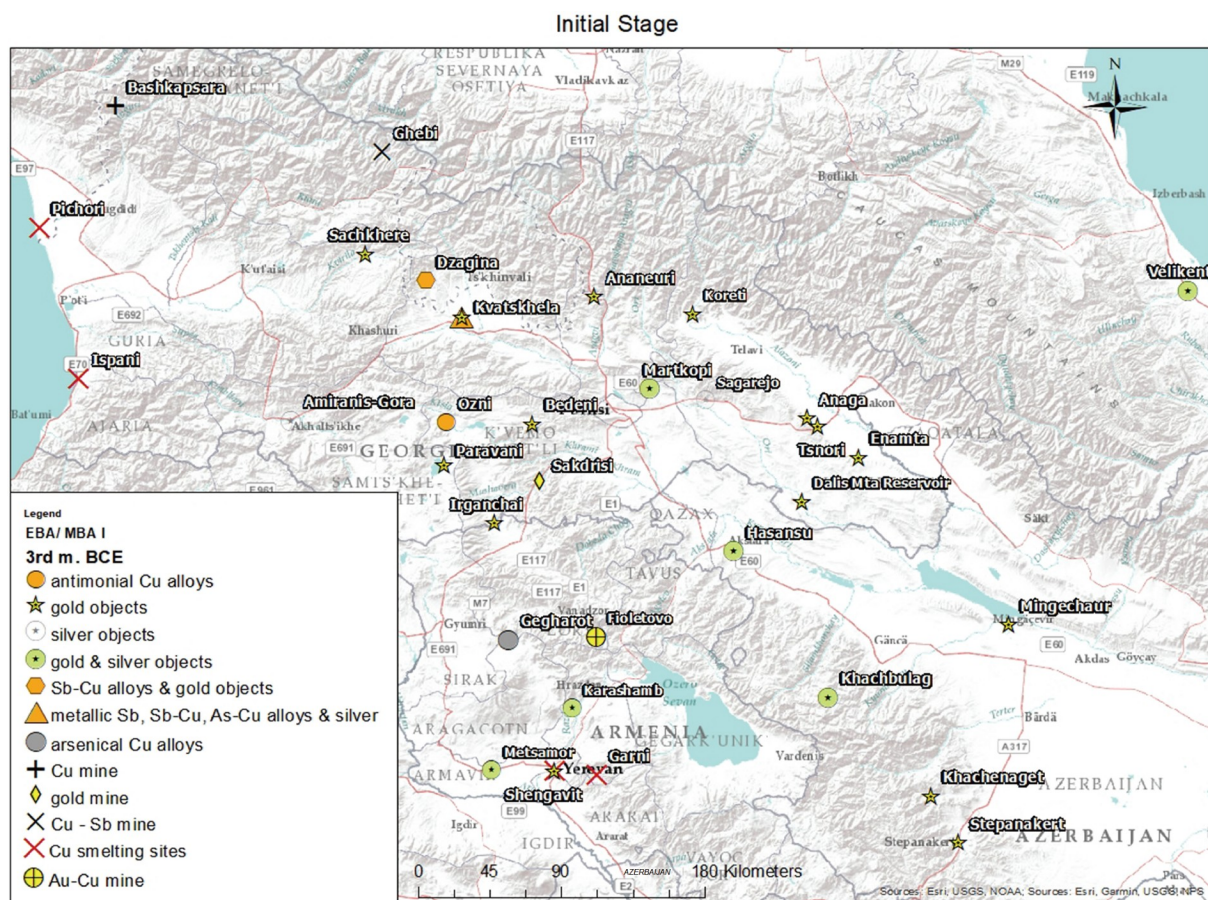


Figure 3 (Color online) Spread of antimony-rich objects, gold and silver objects during the third millennium BCE (initial stage I and II) and the mines in use (straight evidence) during this period (mapped in ArcGIS by the author).

and the “later” metallic antimony objects (LBA–EIA) is apparent. A disintegration of regional social networks may have ended the arrival of Early Transcaucasian (Kura-Araxes) ceramics (or people) and the diverse obsidians that disappeared from Urkesh (Frahm and Feinberg, 2013).

4. Early adoption stage

From the MBA (2100–1550 BCE) onwards, antimonial copper alloys with 1–20% Sb and sometimes with a similarly high arsenic content predominated in the Caucasian region. In Abkhazia the alloys were also characterised by the presence of zinc. They were mainly assigned to the Trialeti culture (MBA II; 2000–1700 BCE). As the name suggests, the term is derived from the Trialeti area, where most of the Trialeti culture kurgans have been discovered. This diagnostic element of the culture was, however, widespread throughout eastern and southern parts of Georgia and elements of the Trialeti culture have been observed in burials excavated in Armenia and Azerbaijan as well (Chernykh, 1992).

During this period, the art of goldsmithing reached its zenith, especially at sites attributed to the Trialeti culture:

Odzun, Aygeschat, Lchashen, Lori Berd, Aruch, Nerkin Naver, Trialeti, Irganchai, Tabatskuri, Mravaltskali, and Beshtasheni (see Figure 4). Not only gold ornaments were found at these sites, but also gold and silver vessels were discovered (Bobokhyan et al., 2017). At Trialeti itself, a necklace with gold and semi-precious stones dating to the 20th–19th century BCE was found amongst the grave goods. Dating to the 18th–17th century BCE, a footed silver goblet from Barrow 5 and a decorated silver bucket and gold cup from Barrow 17 have also been unearthed (Hauptmann and Gambaschidze, 2001). Other gold and silver vessels were uncovered at Kirovakan and Karashamb (Armenia) (Abramishvili, 2010).

Next to the already operational mine of Sakdrisi, the gold mines of Sotk, located at 2100–2500 m.a.s.l., were exploited from the second millennium BCE onwards, as illustrated by many pits, underground workings, wooden parts of working tools, stone mortars for working ores, stone washing pots, and slag (Bobokhyan et al., 2017). In the Great Caucasus, mining and metallurgical evidence dating to around the 19th century BCE (1895–1748 cal BCE) was attested at Sagebi Dziri (Kushnareva, 1993). The evidence is described as a white opaque glassy material, consisting of nearly pure

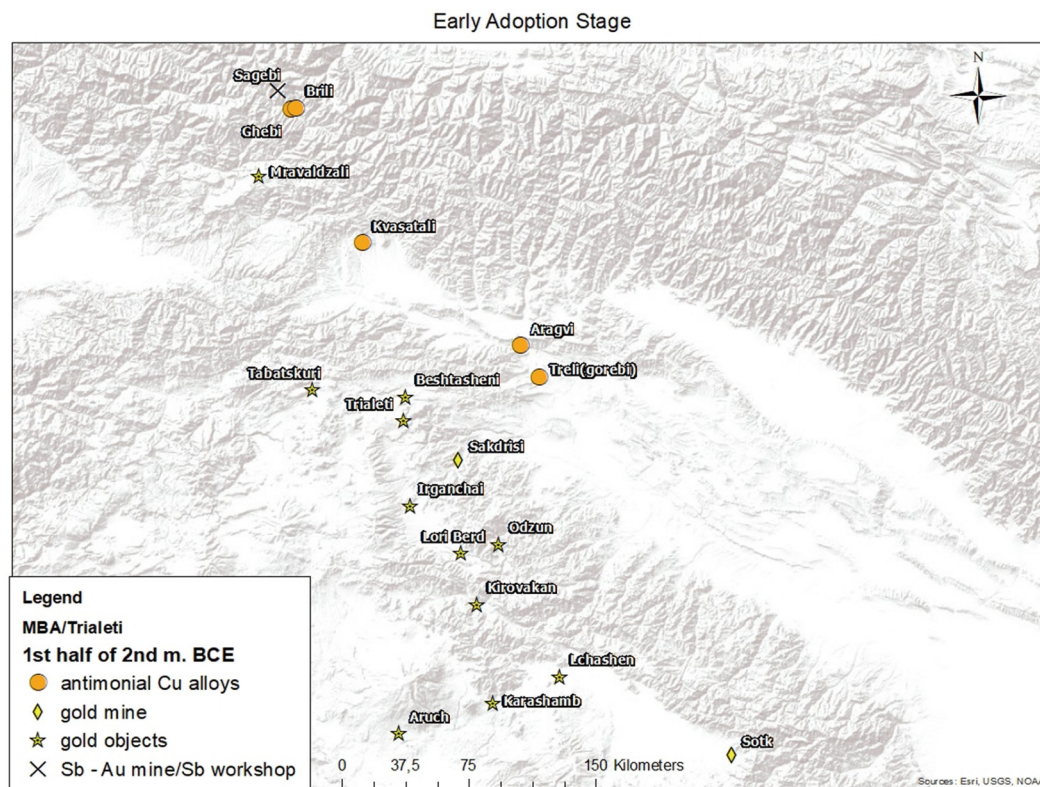


Figure 4 (Color online) Spread of antimony-rich objects and gold objects during the first half of the second millennium BCE and the mines in use (direct evidence) during the Trialeti period (mapped in ArcGIS by the author).

quartz with streaks of pure metallic antimony (Degryse et al., 2015). It is most likely a metallurgical waste product of antimony extraction. Sagebi is also one of the main gold bearing complexes in the Caucasus (Kekelia et al., 2008), meaning that next to antimony, also gold could have been mined and processed there.

The early adoption stage can hence be dated to the turn of the third to second millennium BCE and the first centuries of the second millennium BCE, i.e., ca. 2100–1700 BCE, which corresponds more or less with the Trialeti culture in the region.

The abundance of gold grave goods during the MBA in the southern Caucasus represents a paradoxical situation (Bokhyan et al., 2017). During the prequel stage, many golden objects attributed to the Maikop Culture were attested in the northern Caucasus (Hansen, 2014), while the more systematic presence of gold objects in the southern Caucasus started only during the first half of the third millennium BCE, here labelled as the initial stage of antimony metallurgy. During the early adoption stage the attestation of gold objects in the southern Caucasus increased, while they disappeared in the northern Caucasus. Since it is not clear where the gold originally derived from in the northern Caucasus during the Maikop culture, an origin from the same mines in the southern Caucasus is a plausible option for the above-mentioned gold objects during the MBA. This chronological and

geographical gap between the production of the first gold objects during the Maikop culture in the northern Caucasus and the gold objects and antimony-rich—likely—“alternatives” in the southern Caucasus might indicate that the push mechanism of the visual aspect was not the only driving force for the uprising of antimony use. First of all, an archaeological bias due to the nature of burial practices, i.e., different funerary traditions between the northern and southern Caucasus, can cause a “misreflection” of the material culture. The connections of both regions, of which the southern Caucasian was inherently more connected with the Near East (Shanshashvili and Narimanishvili, 2012), while the northern Caucasus had more contact with eastern Europe, could also contribute to a difference in material culture. Based on linguistic arguments, it has even been argued that Hurrian-speaking people, who lived in northern Mesopotamia during the Bronze Age, originated in the Caucasus (e.g., Stein, 1999; Steinkeller, 1998) and were either immigrants or invaders (e.g., Wilhelm, 1989; Steinkeller, 1998).

These connections, reflected in the material culture, and imported products discovered on sites and cemeteries, as well as some cultural innovations, indicate a strong relation between the population of this region and civilizations in the Near East, Mesopotamia and the eastern Mediterranean (Shanshashvili et al., 2010; Shanshashvili and Narimanishvili, 2012, 2016). It is tempting to describe these

interactions as transfer of the Near Eastern cultural achievements (e.g., fast potter's wheel, metallurgical techniques, advanced balance weights,... (Avetisyan and Bobokhyan, 2012; Bobokhyan et al., 2017)) to the people of the Caucasus, and in turn, export of regularly utilised raw materials such as copper, lead, antimony and obsidian. However, the Caucasus was not only a consumer of luxury products. To give an example, it is suggested on the basis of archaic elements of the south Caucasian rapiers that these weapons originated in the region itself and spread to the Aegean via Anatolia (Abramischvili, 2010). Hence, what emerges from this mix of influences is hybridity. In Trialetian goldsmithery different cultural traditions can be distinguished, which supposedly were the result of the merging and transformation of multiple local and near eastern traditions of artistic craft (Makharadze, 2014).

The developments were related to changes, which took place in the socio-economic relations and political processes at the end of the third and beginning of the second millennium BCE. Economically, in the Near East the value system changed over time, from copper over silver to gold (Bobokhyan et al., 2017). Also, politically, changes had obviously an influence on trade relations. The existence of Mesopotamian trade colonies in Anatolia, such as Kültepe/Kaneš and Norşuntepe, which lie north of the Taurus Mountains in the Cappadocia region of central Turkey, connected the southern Caucasus with the East. Therefore, when Shamshi-Adad I (1809–1776 BCE by the middle chronology) of the Old Assyrian Empire (2000–1600 BCE) locked all the roads going along the Euphrates, Tigris and the Zagros mountains, he disturbed the caravan trade throughout the whole East. Within Lower Mesopotamia the increasing dominance of Amorite dynasties is notable, with Amorite kings being established at many major cities, including Babylon, Kish and Uruk. Hammurabi of Babylon (1792–1750 BCE by the middle chronology) even created a state that almost transcended traditional city-state rivalries. In 1761 BCE he defeated Zimri-Lim in battle and captured the city of Mari, a very important place in international trading, and finally destroyed it in 1757 BCE. Meanwhile, the Old Assyrian Empire in Anatolia collapsed in the mid-18th century BCE. Kaneš (Kültepe) was sacked in ca. 1760 BCE, probably due to conflict between local kingdoms. Other Old Assyrian trade sites were also destroyed at this time, as demonstrated by the burning of the two great MBA palaces of Acemhöyük, west of Kültepe (Matthews, 2009).

These political changes had obviously an influence on trade relations. Because of the destruction of cities such as Kültepe/Kaneš and Norşuntepe, the road via Malatya lost its importance. This destruction of colonies and violation of trade routes is often interpreted as the cause of decline of the southern Caucasian MBA cultures (Shanshashvili et al., 2010; Shanshashvili and Narimanishvili, 2012, 2016). It

should however not be forgotten that internally, the social organisation in the southern Caucasus seems to have changed as well. Archaeological evidence shows that the MBA (ca. 2400–1550 BC) in the southern Caucasus was characterised by a clear transition from village-based agrarian life, common to the EBA Kura-Araxes tradition, to mobile pastoralist lifeways (Lindsay and Greene, 2013; Lindsay and Smith, 2006). The profound changes in material culture assemblages, mostly visible in the construction of monumental kurgan burials, and the debut of multiple contemporary ceramic horizons, coincided with the abandonment of settled farming villages at the end of the third millennium BCE and the adoption of new social, economic, and political arrangements associated with mobile cattle herders (Kohl, 1992; Lindsay and Greene, 2013). This in turn might have been affected by the changing climate at the end of the third millennium BCE as well, which will be discussed into more detail for the late adoption stage.

5. Late adoption stage

The end of the Trialeti Culture in Georgia corresponds to the 17th century BCE. The succeeding LBA of Georgia is commonly expressed as “Late Bronze–Early Iron Age (EIA)”. There is no formal break of the beginning for the EIA, but the LBA can be dated to 1500–1150 BCE, the EIA to 1150–1000 BCE. In the east of the Transcaucasian region, there appears first the Baret culture (1500–1350 BCE), followed by the Central Transcaucasian Culture (mid-14th and 13th century BCE), followed in turn by the Samtavro culture (12th–11th century BCE) and the Lchashen-Tsitelgori culture (1500–800 BCE) (Chernykh, 1992; Sagona, 2017). Of these, the former three are confined to the borders of modern Georgia. The latter is more widespread, with evidence from Armenia, western Azerbaijan and NE Turkey. During the LBA-EIA, the Caucasus is one of the richest metalworking areas of the Old World, with tens of thousands of tin-bronze artefacts unearthed in excavations (Chernykh, 1992).

It was not before the 17th century BCE that the southern Caucasus saw the blooming of antimony metallurgy, and what we could describe as the final phase in the invention-adoption process. During this period, the use of antimony-rich alloys became even more widespread in the Caucasian region, especially in the northern Koban area (Pike, 2002), while it was replaced with bronzes with a high content of tin in the Lchashen-Tsitelgori culture (Sagona, 2017). In Grave 12 at Brili, multiple objects (axe and pendants) made of Sb-As-Cu alloy have been found, dating to the 18th–16th century BCE (Abramischvili, 2010). New complex alloys such as Cu-Sb-Pb and Pb-Sb are also found (Meliksetian and Pernicka, 2003). Next to the abundance of antimonial alloys, also metallic antimony beads appear more regularly in ar-

chaeological contexts during the second millennium BCE, indicating deliberate use (see [Figure 5](#) for the attestations). Their use runs far into the LBA, with many attestations up into the 12th century BCE ([Chernykh, 1992](#); [Hauptmann, 2001](#); [Tite et al., 2002](#); [Meliksetian and Pernicka, 2003](#); [Lindsay and Smith, 2006](#); [Meliksetian et al., 2011](#)). From at least 1700 BCE onwards, mining occurs in some of the antimony-rich deposits, such as Sagebi (1895–1748 cal BCE; 1882–1698 cal BCE) and Zopkhito (1379–1167 cal BCE; 1517–1083 cal BCE) in the Racha region ([Chernykh, 1992](#); [Kushnareva, 1993](#)). The polymetallic deposit Zaargashi revealed two shafts with discarded tools and tailings very similar to the other ones found in the LBA mines of the Racha region (information obtained during personal visit to the Mestia museum). Therefore, the Zaargashi mine is considered LBA in date. The copper mine of Bashkapsara was also still in use, based on radiocarbon dates of the western (1750–1318 cal BCE) and northern part (1518–994 cal BCE) of the mine.

Gold is still very popular. In Kurgan 4 at Berikldeebi, dating to the 14th–13th century BCE, silver and gold jewellery has been discovered, as well as frit and glass paste beads. Decorated gold beads dated to the 15th to 14th centuries BCE were found in rich graves at Lchashen, Lori Berd and Metsamor in Armenia. At Lori Berd also a golden disc pendant and a golden button were found ([Piller, 2002](#)).

The late adoption stage can be dated to the latest three quarters of the second millennium BCE, i.e., 1700–1000 BCE.

Analyses of the chemical composition of the metallic metallic bead samples ([Degryse et al., 2020](#)) revealed a division of a high-copper group (i.e., >0.6 wt% Cu) with correlated silver and gold and a low-copper group (i.e., <0.6 wt% Cu) with correlated bismuth. It is worth noting that only beads from Brili belong to the high-copper group, while all the metallic antimony beads coming from Chalipiragorebi belong to the low-copper group. Additionally, three samples from Brili also belong to the latter group. Since in the low-copper group, bismuth is the only associated element, it is suggested that stibnite was used for their production. Conversely, tetrahedrite-tennantite ores have a different S/Sb ratio, and an association with mainly copper next to arsenic, iron and zinc (as it often substitutes in the structure). This association is clearly visible in the high-copper group, but these beads are still composed of 70–80% Sb and only around 2% Cu, meaning that either they were made of highly pre-processed tetrahedrite-tennantite ores or another stibnite deposit rich in copper, different to the low-copper group beads. This situation fits into the model of “independent mining” as phrased by [Erb-Satullo et al. \(2017\)](#), describing the extraction of ores by either different groups of miners, or by the same group of miners exploiting a constellation of mining sites. Since here multiple sources were used si-

multaneously ([Degryse et al., 2020](#); [Dillis et al., 2019](#)), especially in the case of Brili, the ores were obtained by different groups of miners or different ore deposits were exploited in different mining campaigns over time. Likewise, for the copper smelting sites in the Supsa-Gubazeuli area (Colchis, western Georgia), radiocarbon dated to about 1300–800 BCE, the organisation of independent groups of metalworkers exploiting multiple parts in a zoned ore body was identified. It was suggested that these different groups of people carried out primary production independently. Though they may have shared technological practices, evidence for more sustained coordination or top-down organisation in copper production is minimal ([Erb-Satullo et al., 2017](#)).

The correlation of the high-Cu beads with traces of Ag and Au is interesting. It might indicate that the gold and antimony metallurgies were intertwined/interlinked. It matches with the framework of ethnocategories based on perceptual characteristics ([Mödlinger et al., 2017](#)). Gold, antimony metallic beads and antimonial Cu alloys are all “shiny yellow” in colour, which may have served as pull mechanism for the step to full adoption. In line with this, the onset of glass production, which sees the immediate and almost simultaneously use of both calcium and lead antimonates, could have increased the demand from the South as a push factor. As lead antimonate is yellow it might have served as an alternative for gold ([Shortland, 2002b](#)), and hence it is not so farfetched to consider the associations of “yellow” with gold and antimony.

The glass industry runs mainly parallel to antimony metallurgy in the southern Caucasus. The beginning of glass production dates back to the second half of the third millennium BCE, with irregular finds of small glass objects, in both the Levant and Mesopotamia. This initial stage passes into the early adoption stage in the first half of the second millennium BCE with a growing number of finds in Anatolia, Levant and Mesopotamia (Iran) ([Henderson, 2013](#); [Moorey, 1988, 1999](#); [Shortland, 2012](#)). A tipping point might be seen in the glass findings at Dinkha Tepe, dating to 1800–1600 BCE ([McGovern et al., 1991](#)). Finally, glass production became mainstream from the 16th century BCE onwards in Egypt, the Levant, Mesopotamia, Anatolia, Greece and the Caucasus ([Shortland, 2012](#)). The demand for antimony to produce the antimony-rich opacifiers could have triggered the Caucasian miners and metalworkers to look for and work more intensively with antimony metals.

Although the Caucasian LBA is well known for the high quality of objects made of various types of alloys, gold and silver, as well as by the use of new metal technologies, there is no major evidence of metal production facilities. There is, however, evidence for mining in the Racha-Lechkumi area and the Svaneti region as a whole and the findings of metallic antimony beads itself. The lack of major evidence of antimony and other metal production might be associated with

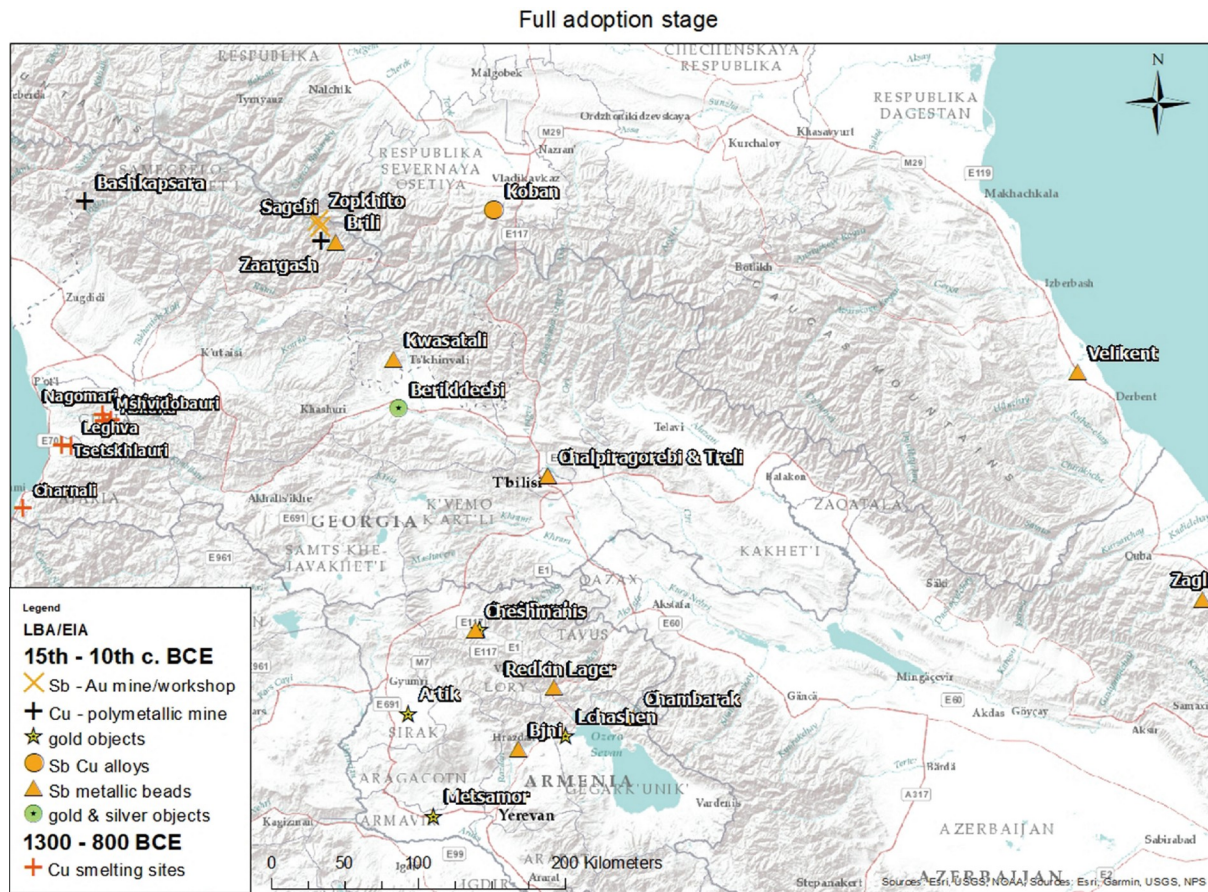


Figure 5 (Color online) Dispersal of gold, silver and antimony-rich objects with the attestations of mines and smelting sites (mapped in ArcGIS by the author).

the decrease of sedentary lifestyles. This leads to an aspect of pastoralist mobility that can be put forward as an important factor in the distribution of antimony raw materials. For a long time, ethnographers and archaeologists saw mobility as an impediment to social complexity, one that either prevented the development or the continuation of larger political units, and that only had to be managed by sedentary populations in particular ways. In contrast, novel theoretical approaches in archaeology have begun to consider the ways in which pastoralist mobility (especially long-distance seasonal migration) can foster organisational complexity and large-scale political communities (Chazin et al., 2019).

The LBA in the southern Caucasus is generally understood as a period during which there were significant changes in political and social organisation, following a period of (assumed) pastoral nomadism in the MBA. The mid-second millennium BCE witnessed the construction of large enclosed hilltop sites with accompanying cemeteries (e.g., Beshkenasheni, Sabechedavi, Knole, Utsklo, etc.) and the sacro-institutional contexts of craft production, storage, and consumption behind their cyclopean walls (Shanshashvili and Narimanishvili, 2012). It suggests an investment in the built environment and place-making during the LBA that

stands in stark contrast to the dearth of settlement remains in the MBA. This has been interpreted as not only marking a significant change in political organisation with the first “complex” polities in the region, but also the reappearance of a more settled mode of life and the transition to an agricultural economy (Smith et al., 2004). Yet, some of these so-called “fortresses-cemeteries” are already dating back to the MBA, e.g., Oğlanqala and Elmakaya (Shanshashvili and Narimanishvili, 2012). Moreover, there is indirect evidence from archaeological survey and excavations, e.g., at Gegharot and Tsaghkahovit which suggests that mobile pastoralism (for the theoretical approach followed in this paper, see Chazin et al., 2019) remained important throughout the LBA. For these hilltop sites in the Tsaghkahovit Plain, in particular, evidence shows that it was occupied short-term by mobile pastoralists (Lindsay and Greene, 2013). Strontium isotopic research by Chazin et al. (2019) indicates that large-scale regional movements from the Tsaghkahovit Plain, especially south into the Ararat Plain were not common, although the isotopic data do not exclude geographic or vertical seasonal mobility within isotopically-similar regions. Hence, these hilltop sites likely administered political institutions for communities with significant commitments to

maintain practices of movement and intermittent residency. These fortresses served as binding forces for the geographically dispersed members of a group in “integrated communities” (Lindsay and Greene, 2013).

Due to the mountainous environment of the Racha-Lechkhumi region in the Greater Caucasus, a certain degree of vertical mobility, both of animals and humans, under the form of transhumance can be expected. This is seasonal movement of livestock between fixed summer and winter pastures. In montane regions, people react to seasonal changes in the resources, and so the mobility implies movement between higher pastures in summer and lower valleys in winter (so-called vertical transhumance, mountain nomadism, or alpine pastoralism). These mountain economies are characterised by permanent villages, typically in valleys, a vertically organised summer pasture system and are based on dynamic households, whose members act as semi-autonomous units. This seasonal movement is embedded in a system of economic diversification aimed at the reduction of risks and maximisation of profit, which is a common feature of remote mountainous regions (Knipper et al., 2008).

In the Greater Caucasus, various peoples still practice transhumance related to sheep farming to varying degrees. In general, a family's life is structured around a yearly cycle with marked periods of absence and presence. Even if the herders spend more time outside of the household they are still involved in the household activities and participate with their families in certain core events such as festivals or funerals (Mühlfried, 2014). For instance, the Tushetian village mountain Omalo is only inhabited during the summer months, while for the winter months every household of the entire village moves down to the valley 60 km further. The shepherds still take their flock down by foot, having to cross the 2826 m high Abano Pass from the mountains of Tusheti to the plains of Kakheti, whilst the rest of the family goes down by truck over the Military Road, taking all their belongings with them (from personal observations).

This way of life of the prehistoric Caucasian populations, probably practising vertical transhumance, aligns with the independent mining model. A picture of seasonal metal production emerges, characterised by intermittent smelting episodes in which different ore outcrops were exploited at different times (Erb-Satullo et al., 2017). Metalworkers were moving between lowland areas and mountain zones and practiced seasonal smelting due to climatic factors, as too much rain would make it difficult to carry out smelting year-round and snow would prevent access to mines at higher elevations in the winter. For instance, the smelting evidence at Sagebi indicates a local smelting site was located there (Gambaschidze and Hauptmann, 2013; Degryse et al., 2015). However, due to the altitude and heavy snow fall during winter, the production could simply not have been continuous. Hence, with the moving of these craftspeople, also

the moving of goods can be facilitated. The smelting sites could have served as intermediate nodes between areas. However, this spatial segmentation of the production, away from the settlements and secondary workshops, does not mean social segmentation of metalworkers by production stage. The metalworkers probably moved between lowland and mountainous areas as part of a regular pattern of movement. Even more so, these metalworkers most likely still engaged in herding. For these pastoralists, exchange offered a means for buffering short-term resource shortages, especially for the harsh winter months in the mountains, while it also helped maintaining connections with homeland and kin groups, and providing access to raw materials that were not locally available. Particularly with regard to mineral resources this could be an efficient mechanism: pastoralists, who go up in the mountains with their herds during the summer pass by these mineral deposits/mines, while during winter they go down to the valleys where they can exchange/trade the ores for other goods. It could have allowed the diffusion of metallurgical activities, technical principles, and raw material (e.g., as ores or ingots).

Cribb (1991) documented the migrations of the nomadic and semi-nomadic Alikan tribes across southeastern Turkey. The different groups' routes crossed, often at cities where goods could be traded, creating an intersecting de facto exchange network (Cribb, 1991). Likewise, transhumance is perhaps the most discussed mechanism of obsidian distribution in Eastern Anatolia (e.g., Hole, 1968; Wright, 1969; Williams-Thorpe, 1995; Cauvin, 1996; Chataigner, 1998; Chataigner et al., 1998 in Frahm and Feinberg, 2013).

On a larger scale, the appearance of powerful political units in Asia Minor and Mesopotamia in the second millennium BCE and the changing political situation definitely had an influence on the trade and exchange system. Because of this, one of the main trade routes leading to Mesopotamia shifted to the east coast of Lake Van, or to the west coast of Lake Urmia, passing the river Little Zab and crossing Arbela to Upper Mesopotamia. From the second half of the second millennium BCE or “Mittelsyrian period”, exchanges between the southern Caucasus and the Near East were probably carried out on these roads along the Van and Urmia lakes. Many commercial hubs such as Qatna and Tell Mozan were under control of the Mitannian empire (Matthews, 2009). Supposedly, the relations of the southern Caucasus with Mesopotamia, Syria and Iran were established through the mediation of the Mitanni kingdom (see Figure 6). This may mean, once the raw materials and smelted metallic antimony beads were exchanged by the pastoralists in the lowlands, these goods could have easily found their way south into the Mitanni kingdom, and even Egypt, to supply the glass workshops. Likewise, glass objects found their way into the Caucasian region, even into the Greater Caucasus, where for instance at Brili an Egyptian glass scarab has been

found. Glass beads from Narekvavi, close to Mtskheta and dated to the 12th century BCE revealed a composition consistent with Mesopotamian glass (Dillis, 2020).

6. The aftermath

To the authors' knowledge, a gap is observed in the archaeological record for antimony-rich alloys and metallic antimony objects between 1100 and 1000 BCE. During the 9th and 8th century BCE metallic antimony beads have been found again in the southern Caucasus (e.g., Chambarak), the Near East (e.g., Hasanlu, Tell el Farah, Yoncatepe) and in Egypt (e.g., Lahun). At Naukratis (Egypt), the latest examples, two weights, are attested, dating to 630–300 BCE. Interestingly, these two objects are consistent with an Armenian origin, of which one could be specified to Lori. In this particular case, the eastern Greek colonies might have mediated the exchange towards the harbour of Naukratis (Masson-Berghoff et al., 2018). Also, starting from the 6th century, as a confrontation between Byzantium and Iran started, the Caucasian route gained importance. This provided a road network again, linking up the southern Caucasus with the Near East, Egypt, and even the steppes further East (Frankopan, 2015). Asian merchants, that provided By-

zantium with Chinese silk, tried to explore new routes, relying on much older networks such as the “Koban” Central Transcaucasian route that led through the Darial gorge in North Ossetia, or via the Derbent pass and the western Caucasian routes that led along the Caspian Sea (Chshiew, 2017).

7. Conclusion

Antimony ores were frequently used as a raw material in antiquity. Considering the assumption that the broader Caucasian region is the likely origin of the antimony used as an opacifier in ancient glass making (e.g., Shortland, 2002b; Dillis et al., 2019; Degryse et al., 2020), and since the innovation of antimony metallurgy seems to be confined to the southern Caucasus, this paper has focused on the invention-innovation of antimony metallurgy, its chronological framework, mechanisms and motives in the Greater and southern Caucasus. The work presented indicates that mining was carried out on a small scale at numerous different outcrops in the Racha–Lechkumi region. The possibility of Anatolian ores cannot be excluded. However, according to the available archaeological data at present, only Caucasian mines (Zopkhito and Sagebi) rich in antimony were already exploited as early as 1700 BCE.

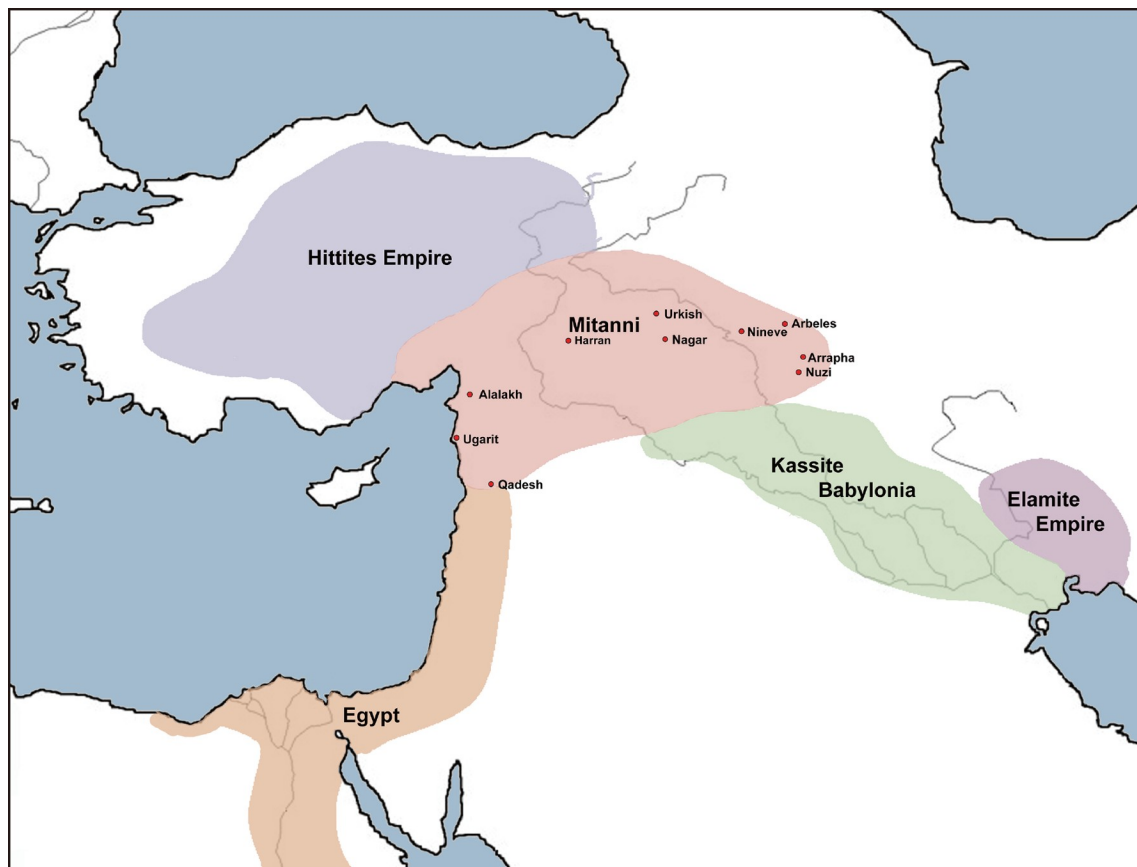


Figure 6 (Color online) Map showing the Kingdom of Mitanni at its greatest extent ca. 1400 BCE (mapped by Mike Carremans).

The development of antimony in metallurgy in the southern Caucasus was described based on the Childe/Snodgrass stage-based model. A prequel stage can be seen in the local mining and metallurgy of gold and silver, dating to the second half of the fourth to the beginning of the third millennium BCE. Based on the chronological framework of the initial stage I, this pre-existing knowledge of gold mining and processing might have formed the basis in which the invention of antimony use in metallurgy sets off, at first characterised by antimonial copper alloys, during the first half of the third millennium BCE. During the initial stage II starting during the mid-third millennium BCE, the first metallic antimony beads in the southern Caucasus appear. These are still rare. However, of gold ornaments become plentiful. The antimony-rich, gold and silver objects were likely produced in a cross-craft interaction context that was pushed by the demand of the consumer based on the perceptive characteristics. It is likely that at this stage antimony minerals were beginning to be considered as a commodity for the production of ornaments having some kind of desirable property, i.e., a colour resembling silver and gold. Antimony minerals might have been used for imitating precious materials or were considered the same as silver and gold based on their visual characteristics. The movement of people from the southern Caucasus into Anatolia and parts of Mesopotamia might have spread the occasional antimony beads outside the Caucasus in the third millennium BCE. This moving seemed to have ceased at the end of the third millennium BCE and might have been triggered by the development of the Akkadian Empire in Mesopotamia in combination with climate changes leading to a disintegration of regional social networks. The early adoption stage corresponds more or less with the Trialeti culture (ca. 2100–1700 BCE). This period is characterised by the exquisite and abundantly present gold ornaments, and gold and silver vessels are found. Direct evidence for antimony use in metallurgy dated to ca. the 19th century BCE at Sagebi Dziri, suggesting the mine with antimony-rich ores was in use during this period. The gold mines of Sakdrisi and Sotk were operational contemporaneously, and Sagebi might also have delivered gold, next to antimony ores. Intense connections with other civilisations in the Near East, the eastern Mediterranean and Mesopotamia during this stage is reflected in the material culture of the southern Caucasus. It remains unclear how these connections unfolded: through down-the-line trade, movement of people, tribute, direct trade, and so on. However, based on the material assemblages, these contacts have been interpreted as a mutual exchange of goods and ideas, resulting in hybridity with a mix of influences. The developments related with political and socio-economical changes at the end of the third and beginning of the second millennium BCE. Mesopotamian trade hubs such as Kültepe and Norşuntepe connected the southern Caucasus

with the Near East. Therefore, when political actions blocked the caravan trade and these hubs were destroyed in the 18th century BCE, these events certainly also affected the Caucasian region. It is often suggested that the decline of the MBA cultures of the Caucasus were even caused by these circumstances. Nonetheless, the internal affairs in the Greater and southern Caucasus cannot be neglected. Profound changes in the material culture and the abandonment of settled farming villages at the end of the third millennium BCE indicate the adoption of new social, economic and political arrangements associated with a mobile pastoralist lifeway. Succeeding these events is the start of the late adoption stage, dating to ca. 1700–1000 BCE, characterised by the zenith of antimony use in metallurgy in the southern Caucasus. Next to the abundant findings of gold and antimony metallic jewellery, also evidence of mining the antimony-rich deposits is found at Sagebi, Zopkhito and Zaargashi. The geochemical data of the sampled beads likely reflect different sources and fit into the model of “independent mining”. The correlation of the high-copper group with silver and gold is very interesting as it indicates that these industries were likely intertwined, a hypothesis that was already coined for the early adoption stage. Besides, an interrelation with the glass industry is suggested. Interestingly, the glass industry runs mainly parallel to the development of antimony metallurgy in the southern Caucasus, while the demand for antimony to produce the antimony-rich opacifiers could have triggered the Caucasian miners and metalworkers to look for and work more intensively with antimony metals. The onset of glass production, which sees the immediate and almost simultaneous use of both calcium and lead antimonates, could have increased this demand. By this time, antimony minerals seem to have been a commodity for both the metal (e.g., metallic beads) and glass industry, in which antimony was used to imitate precious materials. However, how and in what form antimony reaches the glass industries of Mesopotamia and Egypt, remains subject to further investigation. The way of life of the prehistoric Caucasian populations, probably (semi-)nomadic and practising vertical transhumance, could have facilitated the moving of goods. The appearance of powerful political units in Asia Minor and Mesopotamia in the second millennium BCE definitely influenced the trade and exchange system. Many commercial hubs were under control of the Mitannian Empire and it is suggested that the relations of the southern Caucasus with the regions to the south were mediated through the Mitanni Kingdom. In this way, the antimony raw materials may have found their way easily into the regions where the first supposedly glass workshops were situated (Shortland et al., 2018). In return, glass objects travelled back to the Caucasian region. As such, a preliminary link between the development of the metal (antimony, gold) and glass industries can be supposed, and exchange or trade in

antimony is suggested over long distances. It is clear that the southern Caucasus was part of an interlocking and inter-connecting world long before it became part of the Silk Road from the 6th century onwards.

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References

- Abramishvili M. 2010. In search of the origins of metallurgy—An overview of South Caucasian evidence. In: Hansen S, Hauptmann A, Motzenbäcker I, Pernicka E, eds. *Von Majkop bis Trialeti: Gewinnung und Verbreitung von Metallen und Obsidian in Kaukasien im 4.-2. Jt. v. Chr. Beiträge des Internationalen Symposiums*. Berlin: 323
- Abramishvili R, Abramishvili M. 1995. Archäologische Denkmäler in Tbilisi. In: Miron A, Orthmann W, eds. *Unterwegs zum goldenen Vlies. Archäologische Funde aus Georgien*. Stuttgart: Museum für Vor- und Frühgeschichte Saarbrücken. 185–205
- Avetisyan P, Bobokhyan A. 2012. Archaeology of Armenia in regional context: Achievements and perspectives. In: Avetisyan P, Bobokhyan A, eds. *Archaeology of Armenia in Regional Context*. 7–20
- Avilova L I. 2008. Regional models of metal production in Western Asia in the Chalcolithic, Early and Middle Bronze Ages. *Trabajos de Prehistoria*, 65: 55–73
- Batiuk S D. 2013. The fruits of migration: Understanding the 'longue durée' and the socio-economic relations of the Early Transcaucasian Culture. *J Anthrop Archaeol*, 32: 449–477
- Ben-Yosef E, Vassal Y, van den Brink E C M, Beeri R. 2016. A new Ghassulian metallurgical assemblage from Bet Shemesh (Israel) and the earliest leaded copper in the Levant. *J Archaeol Sci-Rep*, 9: 493–504
- Bobokhyan A, Kunze R, Meliksetian K, Pernicka E. 2017. Society and metal in Bronze Age Armenia. In: Rova E, Tonussi M, eds. *At the Northern Frontier of Near Eastern Archaeology*. Brussels: Brepols. 501–524
- Cambi L, Cremascoli F. 1957. Sul metallo dei bottoni della tomba preistorica di Monte Bradoni presso Volterra. *RendIstLomb*, 91: 371–377
- Chazin H, Gordon G W, Knudson K J. 2019. Isotopic perspectives on pastoralist mobility in the Late Bronze Age South Caucasus. *J Anthrop Archaeol*, 54: 48–67
- Chen K, Rehren T, Mei J, Zhao C. 2009. Special alloys from remote frontiers of the Shang Kingdom: Scientific study of the Hanzhong bronzes from southwest Shaanxi, China. *J Archaeol Sci*, 36: 2108–2118
- Chernykh E N. 1992. *Ancient Metallurgy in the USSR: The Early Metal Age*. Cambridge: Cambridge University Press
- Childe V G. 1944. Archaeological ages as technological stages. *J R Anthropological Inst Great Britain Ireland*, 74: 7–24
- Chshiew V. 2017. The transcaucasian silk road in the Late Bronze and Early Iron Age: The materials of the Koban Archaeological Monuments Found in North Ossetia-Alania. *J Nat Sci Sustain Technol*, 11: 1–14
- Courcier A, Jalilov B, Aliyev I, Guliyev F, Jansen M, Lyonnet B, Mukhtarov N, Museibli N. 2017. The ancient metallurgy in Azerbaijan from the end of the Neolithic to the Early Bronze Age (6th–3rd millennium BCE): An overview in the light of new discoveries and recent archaeometallurgical research. October, 25–36
- Courcier A. 2014. Ancient metallurgy in the caucasus from the Sixth to the Third millennium BCE. In: Roberts B W, Thornton C P, eds. *Archaeometallurgy in Global Perspective: Methods and Syntheses*. New York: Springer New York. 579–664
- Cribb R. 1991. *Nomads in Archaeology*. Cambridge: Cambridge University Press
- Davies O. 1935. Antimony bronze in central Europe. *Man*, 35: 86–89
- De Marinis R C. 1999. Towards a relative and absolute chronology of the Bronze Age in northern Italy. *Notizie Archeologiche Bergomensi*, 7: 23–100
- De Marinis R C. 2006. Aspetti della metallurgia dell'età del Rame e dell'antica età del Bronzo. Toscana. *Rivista Di Scienze Preistoriche*, 56: 211–272
- Degryse P, Lobo L, Shortland A, Vanhaecke F, Blomme A, Painter J, Gimeno D, Eremin K, Greene J, Kirk S, Walton M. 2015. Isotopic investigation into the raw materials of Late Bronze Age glass making. *J Archaeol Sci*, 62: 153–160
- Degryse P, Shortland A J, Dillis S, van Ham-Meert A, Vanhaecke F, Leeming P. 2020. Isotopic evidence for the use of Caucasian antimony in Late Bronze Age glass making. *J Archaeol Sci*, 120: 105195
- Dillis S, Van Ham-Meert A, Leeming P, Shortland A, Gobejishvili G, Abramishvili M, Degryse P. 2019. Antimony as a raw material in ancient metal and glass making: Provenancing Georgian LBA metallic Sb by isotope analysis. *STAR-Sci Tech Archaeol Res*, 5: 98–112
- Dillis S. 2020. Antimony as a raw material for making metal and vitreous materials from the Bronze Age to the Roman period. Dissertation for Doctoral Degree. Leuven: KU Leuven
- Dolfini A, Peroni R. 2010. The origins of metallurgy in central Italy: New radiometric evidence. *Antiquity*, 84: 707–723
- Dolfini A. 2014. Early metallurgy in the central Mediterranean. In: Roberts B W, Thornton C P, eds. *Archaeometallurgy in Global Perspective*. New York: Springer. 473–506
- Erb-Satullo N L, Gilmour B J J, Khakhutaishvili N. 2017. Copper production landscapes of the South Caucasus. *J Anthrop Archaeol*, 47: 109–126
- Erb-Satullo N L, Gilmour B J J, Khakhutaishvili N. 2015. Crucible technologies in the Late Bronze–Early Iron Age South Caucasus: Copper processing, tin bronze production, and the possibility of local tin ores. *J Archaeol Sci*, 61: 260–276
- Erb-Satullo N L. 2019. The innovation and adoption of iron in the ancient near east. *J Archaeol Res*, 27: 557–607
- Fleming S J, Nash S K, Swann C P. 2011. The archaeometallurgy of period IVB bronzes at Hasanlu. In: de Schauensee M, ed. *Peoples and Crafts in Period IVB at Hasanlu, Iran*. Philadelphia: University of Pennsylvania Press. 103–134
- Frahm E, Campbell S, Healey E. 2016. Caucasus connections? New data and interpretations for Armenian obsidian in Northern Mesopotamia. *J Archaeol Sci-Rep*, 9: 543–564
- Frahm E, Feinberg J M. 2013. Environment and collapse: Eastern Anatolian obsidians at Urkesh (Tell Mozan, Syria) and the third-millennium Mesopotamian urban crisis. *J Archaeol Sci*, 40: 1866–1878
- Frankopan P. 2015. *The Silk Roads: A New History of the world*. London: Bloomsbury
- Gailhard N, Bode M, Bakhshaliyev V, Hauptmann A, Marro C. 2017. <https://engine.scichina.com/doi/10.1007/s11430-021-9984-4>

- Archaeometallurgical investigations in Nakhchivan, Azerbaijan: What does the evidence from Late Chalcolithic Ovçular Tepesi tell us about the beginning of extractive metallurgy? *J Field Archaeol*, 42: 530–550
- Gailhard N. 2015. Copper mining community in Transcaucasia during chalcolithic and Bronze Ages. *Broadening Horizons*, 4:11–18
- Gambaschidze I, Hauptmann A. 2013. The Bronze Age metallurgy in Southern Georgia: The origin of gold and base metal artefacts. At the Northern frontier of Near Eastern archaeology: Recent research on Caucasia and Anatolia in the Bronze Age. Humboldt Kolleg International Conference. Venice/Venedig, Italy. 9–11/01/2013
- Gambaschidze I, Mindiasvili B, Gogochuri K. 2010. The Oldest metallurgy and mining in Georgia (VI–III Millennium BC). In *Mtsignobari*. Tblisi: Publishing House. 592
- Giardino C. 1998. I metalli nel mondo antico: Introduzione all'archeometallurgia. Laterza. 356
- Golden J, Levy T E, Hauptmann A. 2001. Recent discoveries concerning Chalcolithic metallurgy at Shiqmim, Israel. *J Archaeol Sci*, 28: 951–963
- Golden J. 2014. Who dunnit? New clues concerning the development of Chalcolithic metal technology. In: Roberts B W, Thornton C P, eds. *Archaeometallurgy in Global Perspective: Methods and Syntheses*. New York: Springer New York. 559–578
- Goren Y. 2014. Gods, caves, and scholars: Chalcolithic cult and metallurgy in the Judean Desert. *Near Eastern Archaeol*, 77: 260–266
- Grazzi F, Pallecchi P, Petitti P, Scherillo A, Zoppi M. 2012. Non-invasive quantitative phase analysis and microstructural properties of an iron fragment retrieved in the copper-age Selviciola Necropolis in southern Tuscany. *J Anal At Spectrom*, 27: 293–298
- Hamon C. 2016. Salt mining tools and techniques from Duzdaği (Nakhchivan, Azerbaijan) in the 5th to 3rd millennium B.C. *J Field Archaeol*, 41: 510–528
- Hansen S. 2014. Gold and silver in the Maikop Culture. In: Meller H, Risch R, Pernicka E, eds. *Metalle der Macht-Frühes Gold und Silber. Metals of power-Early gold and silver*. 6. Mitteldeutscher Archäologentag vom 17. bis 19. Oktober 2013 in Halle (Saale), Halle: Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt. 389–410
- Hauptmann A, Gambaschidze I. 2001. Antimon—Eine metallurgische Besonderheit aus dem Kaukasus. In *Georgien. Schätze aus dem Land des Goldenen Vlies*. Ausstellungskatalog. Deutsches Bergbau-Museum Bochum. 150–155
- Hauptmann A, Schmitt-Strecker S, Begemann F, Palmieri A. 2002. Chemical composition and lead isotope of metal objects from the “Royal” Tomb and other related finds at Arslantepe, Eastern Anatolia. *Paléorient*, 28: 43–69
- Hauptmann A. 2001. Antimon/Antimonkupfer. Mitte 2. Jahrtausend v. Chr. In: Gambaschidze I, Hauptmann A, Slotta R, Yalçin U, eds. *Georgien-Schätze Aus Dem Land Des Goldenen Vlies*. Ausstellungskatalog. Deutsches Bergbau-Museum Bochum. 275–285
- Hauptmann A. 2011. Gold in Georgia I: Scientific Investigations into the Composition of Gold. *Anatolian Metal V* (Vol. Beiheft 24):173–186
- Henderson J. 2013. *Ancient Glass: An interdisciplinary Exploration*. Cambridge: Cambridge University Press
- Hsu Y K, Bray P J, Hommel P, Pollard A M, Rawson J. 2016. Tracing the flows of copper and copper alloys in the Early Iron Age societies of the eastern Eurasian steppe. *Antiquity*, 90: 357–375
- Kekelia S A, Kekelia M A, Kuloshvili S I, Sadradze N G, Gagnidze N E, Yaroshevich V Z, Asatiani G G, Doebrich J L, Goldfarb R J, Marsh E E. 2008. Gold deposits and occurrences of the Greater Caucasus, Georgia Republic: Their genesis and prospecting criteria. *Ore Geol Rev*, 34: 369–386
- Killick D. 2015. Invention and innovation in African iron-smelting technologies. *Cambridge Archaeol J*, 25: 307–319
- Knipper C, Paulus S, Uerpmann M, Uerpmann H-P. 2008. Seasonality and land use in Bronze and Iron Age Kakhetia (Georgia). Oxygen and strontium isotope analyses on horse and cattle teeth. *Archäologische Mitteilungen Aus Iran Und Turan*, 40: 149–168
- Kohl P L. 1992. The Transcaucasian “Periphery” in the Bronze Age. In: Schortman E M, Urban P A, eds. *Resources, Power, and Interregional Interaction*. New York: Plenum Press. 117–118
- Kushnareva K K. 1993. The southern Caucasus during the 9th–2nd mill. BCE. The stages of cultural and socioeconomic evolution. Russian Ac. of Sciences, Institute of History of Material Culture
- Kushnareva K K. 1997. *The southern Caucasus in Prehistory*. Pennsylvania: University of Pennsylvania Museum
- Kvavadze E, Sagona A, Martkoplshvili I, Chichinadze M, Jalabadze M, Koridze I. 2015. The hidden side of ritual: New palynological data from Early Bronze Age Georgia, the southern Caucasus. *J Archaeol Sci-Rep*, 2: 235–245
- Leek R. 2014. The development of iron technology in the Mediterranean Bronze Age. Thesis for Master Degree. Oslo: University of Oslo
- Lemcke G, Sturm M. 1997. ^{18}O and trace element measurements as proxy for the reconstruction of climate changes at Lake Van (Turkey): Preliminary results. In: Dalfes H, Kukla C, Weiss H, eds. *Third Millennium BC Climate Change and Old World Collapse*. Berlin: Springer. 653–679
- Lindsay I, Greene A. 2013. Sovereignty, mobility, and political cartographies in Late Bronze Age southern Caucasia. *J Anthropol Archaeol*, 32: 691–712
- Lindsay I, Smith A T. 2006. A history of archaeology in the Republic of Armenia. *J Field Archaeol*, 31: 165–184
- Lobo L, Degryse P, Shortland A, Vanhaecke F. 2013. Isotopic analysis of antimony using multi-collector ICP-mass spectrometry for provenance determination of Roman glass. *J Anal At Spectrom*, 28: 1213
- Lobo L, Devulder V, Degryse P, Vanhaecke F. 2012. Investigation of natural isotopic variation of Sb in stibnite ores via multi-collector ICP-mass spectrometry-perspectives for Sb isotopic analysis of Roman glass. *J Anal At Spectrom*, 27: 1304
- Makharadze Z. 2014. The End of the Early Bronze Age in Georgia. *Proceedings of International Conference*
- Masson-Berghoff A, Pernicka E, Hook D, Meek A. 2018. (Re)sources: Origins of metals in Late Period Egypt. *J Archaeol Sci-Rep*, 21: 318–339
- Matthews R. 2009. Peoples and complex societies of ancient southwest Asia. In: Scarre C, ed. *The Human Past: World Prehistory and the Development of Human Societies*. London: Thames & Hudson Ltd
- McGovern P E, Fleming S J, Swann C P. 1991. The beads from tomb B10a B27 at dinkha tepe and the beginnings of glassmaking in the ancient near east. *Am J Archaeol*, 95: 395–402
- McGovern P, Jalabadze M, Batiuk S, Callahan M P, Smith K E, Hall G R, Kvavadze E, Maghradze D, Rusishvili N, Bouby L, Failla O, Cola G, Mariani L, Boaretto E, Bacilieri R, This P, Wales N, Lordkipanidze D. 2017. Early Neolithic wine of Georgia in the South Caucasus. *Proc Natl Acad Sci USA*, 114: 201714728
- Meliksetian K, Kraus S, Pernicka E, Avetissyan P, Devejian S, Petrosyan L. 2011. Metallurgy of Prehistoric Armenia Abstract. *Anatolian Metal V*, 24: 201–210
- Meliksetian K, Pernicka E. 2003. Geochemical characterisation of Armenian Early Bronze Age metal artefacts and their relation to copper ores. *Proc Archaeometal Europe*, 56: 41–58
- Miari M. 1993. S. Pietro (Ischia di Castro-Viterbo). *RivScPr XLV*: 101–166
- Mödlinger M, Kuijpers M H G, Braekmans D, Berger D. 2017. Quantitative comparisons of the color of CuAs, CuSn, CuNi, and CuSb alloys. *J Archaeol Sci*, 88: 14–23
- Mödlinger M, Sabatini B. 2017. Bronze Age Caucasian metalwork: Alloy choice and combination. *J Archaeol Sci-Rep*, 16: 248–257
- Moorey P R S. 1988. The Chalcolithic hoard from Nahal Mishmar, Israel, in context. *World Archaeol*, 20: 171–189
- Moorey P R S. 1999. *Ancient Mesopotamian Materials and Industries: The Archaeological Evidence*. Oxford: Clarendon
- Mühlfried F. 2014. Let's flow! Circular migration and transhumant mobility among the Tushetians of Georgia. *Caucasus Survey*, 2: 14–26
- Novák M, D'Agata A L, Caneva I, Eslick C, Gates C, Gates M H, Girginer K S, Oyman-Girginer Ö, Jean É, Köroğlu G, Kozal E, Kulemann-Ossen S, Lehmann G, Özyar A I, Özyaydin T, Postgate J N, Şahin F, Ünlü E, Yağcı R, Meier D Y. 2017. A comparative stratigraphy of Cilicia. *Al-*

- torientalische Forschungen, 44: 150–186
- Okrostsvardize A, Gagnidze N, Akimidze K. 2016. A modern field investigation of the mythical “gold sands” of the ancient Colchis Kingdom and “Golden Fleece” phenomena. *Quaternary Int*, 409: 61–69
- Orthmann W, Miron A. 1995. Unterwegs zum goldenen Vlies: Archäologische Funde aus Georgien. Saarbrücken: Museum für Vor- und Frühgeschichte
- Pallecchi P, Pecchioli R, Tocci A M. 2002. La necropoli eneolitica della Selvicciola (Ischia di Castro-VT): I vaghi della tomba 23. *PPE Atti*, V: 539–543
- Petitti P, Persiani C, Pallecchi P. 2012. Reperti metallici dalla necropoli della Selvicciola (Ischia di Castro-Viterbo). *Atti Della XLIII Riunione Scientifica IIPP, “L’età Del Rame in Italia”*. Bologna, Italy. 187–194
- Petrie W M F. 1891. *Illahun, Kahun and Gurob*. London: David Nutt
- Pike A W G, Cowell M, Curtis J. 1996. The use of antimony bronze in the Koban Culture. *Historical Metallurgy*, 30: 11–16
- Pike A W G. 2002. Analysis of Caucasian metalwork—the use of antimonial, arsenical and tin bronze in the Late Bronze Age. *Ancient Caucasian and Related Materials in the British Museum*: 89–92
- Piller C K. 2002. The Caucasian connection—Reflections on the transition from the Late Bronze to the Early Iron Age in Northern Iran and its connections to the southern Caucasus. *Schriften Des Zentrums Für Archäologie Und Kulturgeschichte Des Schwarzmeerraumes*. 305–317
- Pollard A M, Liu R, Rawson J, Tang X. 2019. From alloy composition to alloying practice: Chinese bronzes. *Archaeometry*, 61: 70–82
- Radivojević M, Rehren T, Kuzmanović-Cvetković J, Jovanović M, Northover J P. 2013. Tainted ores and the rise of tin bronzes in Eurasia, c. 6500 years ago. *Antiquity*, 87: 1030–1045
- Radivojević M. 2015. Inventing metallurgy in Western Eurasia: A look through the microscope lens. *Cambridge Archaeol J*, 25: 321–338
- Sagona A. 2017. *The Archaeology of the Caucasus: From Earliest Settlements to the Iron Age*. New York: Cambridge World Archaeology
- Schachner A. 2001. Azerbaijan: Eine Terra incognita der Vorderasiatischen Archäologie. *Mitteilungen Der Deutschen Orient Gesellschaft Zu Berlin*, 133: 251–332
- Segal D, Carmi I, Gal Z, Smithline H, Shalem D. 1998. Dating a Chalcolithic burial cave in Peqi’in, Upper Galilee, Israel. *Radiocarbon*, 40: 707–712
- Shalev S, Northover J P. 1993. The metallurgy of the Nahal Mishmar hoard reconsidered. *Archaeometry*, 35: 35–47
- Shanshashvili N, Narimanishvili G, Narimanishvili G. 2010. Trade and Trade Roads between South Caucasus and Near East in 3rd–2nd Millennia B.C. *İzmir: Proceedings of the East Anatolian and Caucasian Bronze Age Cultures*. 31–36
- Shanshashvili N, Narimanishvili G. 2012. Late Bronze/Early Iron Age Sites in Trialeti—External relations and cultural contacts. *Austasch und kulturkontakt im Südkaukasus und seinen angrenzenden regionen in der Spätbronze-/früheisenzeit*, 22: 175–194
- Shanshashvili N, Narimanishvili G. 2016. Dynamics and Nature of the Relations between South Caucasus and the Aegean World in the Bronze Age. *Georgia: Proceedings of the international workshop Aegean World and South Caucasus: Cultural Relations in the Bronze Age*. 11–48
- Shortland A J, Kirk S, Eremin K, Degryse P, Walton M. 2018. The analysis of Late Bronze Age Glass from Nuzi and the question of the origin of glass-making. *Archaeometry*, 60: 764–783
- Shortland A J. 2002a. An antimony bead from Jerablus Tahtani. *Historical Metallurgy*, 36: 1–5
- Shortland A J. 2002b. The use and origin of antimonate colorants in Early Egyptian glass. *Archaeometry*, 4: 517–530
- Shortland A J. 2008. The use and origin of antimonate colorants in early Egyptian glass. *Archaeometry*, 44: 517–530
- Shortland A J. 2012. Lapis lazuli from the kiln: Glass and glassmaking the Late Bronze Age. In: *Studies in Archaeological Sciences (Vol. 2)*. Leuven: Leuven University Press
- Siebenschock M. 1996. Archäometallurgische Untersuchungen zur spät-mittelalterlichen und frühneuzeitlichen Verhüttung von Antimonerzen bei Sulzburg im Südschwarzwald. *Ber. Naturf. Ges. Freiburg i. Br.*, 84/85: 5–26
- Smith A T, Badalyan R, Avetisyan P, Zardaryan M. 2004. Early Complex Societies in Southern Caucasia: A preliminary report on the 2002 investigations of project ArAGATS on the Tsakahovit Plain, Republic of Armenia. *Amer J Archaeol*, 108: 1–41
- Snodgrass A M. 1980. Iron and early metallurgy in the Mediterranean. In: *Wertime T A, Muhly J D, eds. The Coming of the Age of Iron*. New Haven: Yale University Press. 335–374
- Stech T. 1999. Aspects of early metallurgy in Mesopotamia and Anatolia. In: *Pigott V C, ed. The Archaeometallurgy of the Asian Old World*. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology. 59–71
- Stein G. 1999. *Rethinking world-systems: Diasporas, colonies, and interaction in Uruk Mesopotamia*. 2nd ed. Tucson: University of Arizona Press
- Steinkeller P. 1998. The historical background of Urkesh and the Hurrian beginnings in northern Mesopotamia. In: *Buccellati G, Kelly-Buccellati M, eds. Mozan 3: Urkesh and the Hurrians Studies in Honor of Lloyd Cotsen*. Malibu: Undena Publications. 75–98
- Stöllner T, Craddock B, Gambaschidze I, Gogotchuri G, Hauptmann A, Hornschuch A, Klein F, Löffler I, Mindiaschwili G, Murwanidze B, Senczek S, Schaich M, Steffens G, Tamasashvili K, Timberlake S, Jansen M, Courcier A. 2014. Gold in the Caucasus: New research on gold extraction in the Kura-Araxes Culture of the 4th millennium BC and early 3rd millennium BC. *Metals of Power-Early Gold and Silver: 6th Archaeological Conference of Central Germany*. Halle, Germany. 71–110
- Stöllner T, Gambaschidze I. 2011. Gold in Georgia II: The oldest gold mine in the World. In: *Yalcin Ü, ed. Anatolian Metal V (Vol. Beiheft 24)*. 187–200
- Tadmor M, Kedem D, Begemann F, Hauptmann A, Pernicka E, Schmitt-Strecker S. 1995. The Nahal Mishmar hoard from the Judean Desert: Technology, composition, and provenance. *Atiqot*, 27: 95–148
- Thornton C P. 2007. Of brass and bronze in prehistoric Southwest Asia. In: *La Niece S, Hook R D, Craddock P T, eds. Metals and Mines: Studies in Archaeometallurgy*. London: Archetype Publications. 123–135
- Tite M S. 2002. The development of vitreous materials in the ancient Near East and Egypt. *U155609(8)*: 585–593
- Tite M, Shortland A, Paynter S. 2002. The beginnings of vitreous materials in the Near East and Egypt. *Acc Chem Res*, 35: 585–593
- Wick L, Lemcke G, Sturm M. 2003. Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: High-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. *Holocene*, 13: 665–675
- Wilhelm G. 1989. *The Hurrians*. Warminster: Aris & Phillips
- Wolf D, Borg G, Meliksetian K, Allenberg A, Pernicka E, Hovanissyan A, Kunze R. 2013. Neue Quellen für altes Gold. *Veröffentlichungen des Landesamtes für Denkmalpflege und Archäologie Sachsen-Anhalt*, 67: 27–44
- Yener K A, Sayre E V, Joel E C, Özbal H, Barnes I L, Brill R H. 1991. Stable lead isotope studies of central taurus ore sources and related artifacts from eastern mediterranean chalcolithic and Bronze Age sites. *J Archaeol Sci*, 18: 541–577
- Zanini A. 2002. Gli oggetti di ornamento del Fontino. In: *Vigliardi A, ed. La grotta del Fontino. Una cavità funeraria eneolitica del Grossetano*. 203–228

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