
Tracing Traditions:

Patterns of technological innovation and the
circulation of copper in Southwest Asia from the 8th to
1st millennia BCE

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Trinity Term 2018

A dissertation in partial fulfilment of the requirements for the degree of Doctor of
Philosophy at the University of Oxford

“The History of every Major Galactic Civilisation tends to pass through three distinct and recognisable phases, those of survival, enquiry, and sophistication, otherwise known as the Who, Why, and Where phases. For instance, the first phase is characterised by the question ‘How can we eat?’, the second by the question ‘Why do we eat?’, and the third by the question ‘Where shall we have lunch?’”

Douglas Adams *The Restaurant at the End of the Universe*

Acknowledgements

The biggest and most heartfelt thanks go to my supervisors. To Prof Pollard for his help with the structure and development of this thesis, for the occasional fascinating tangent about the behaviours of metals in our meetings, and the wealth of knowledge he is always willing to share. I also want to thank him for his understanding and kindness with the various issues that several bouts of unwellness have thrown up over the last few years. To Dr Pete Hommel, thank you for taking me on when the whole thing was a bit of a mess, for diligently going beyond the call of duty and helping me unpick the tangle I had previously weaved and putting it all back together again, and for having so much patience while I panicked at you in endless emails (oh, and for helping me steer clear of “interpretive howlers”!). From now on you can avoid all emails I send you!

To Dr Brian Gilmour and Dr Pete Hommel (again!), for their collection of chemical data from the Caucasus and for letting me use it – thank you. The same thanks goes to Dr Aurélie Cuénod for allowing me to access and utilise the database she collected for her DPhil thesis. To Dr. Pete Bray who has been there since the beginning and has sacrificed many an otherwise promising looking hour at the pub to helping me understand the ‘Oxford System’. To Dr Laura Perucchetti for her help with the legacy data and its various codes that were beyond me, and also to the rest of the FLAME team. Special thanks to Ina St George and Aidan Robinson, without whose plans of a weekly write up session in a café or daily FaceTime accountability, I would completely have missed the deadline.

I would like to thank my family who have supported me in so many wonderful ways for so many years. The most frequent, though by no means the most important, help my parents have given me is in tirelessly removing the overused, superfluous commas incessantly dotted throughout this thesis and checking that my sentences actually make sense (not to mention astute observations such as the fact that it is not called an ‘asterix’). They and my sisters (and my brother in law) have listened to me alternately moan, wax lyrical, and despair about this research for six years. And I thank them for that stoic kindness, which can clearly only be borne out of love. You are all the very best.

The Linacre Lunch Crew, now sadly dissolved, have kept me sane over the years, boosted my confidence when it needed it, helped me through many dark days, and even turned many of those into memories that sparkle. Laura, Dansie, Roger, Meghan, Ellie, Matt, Aidan, Anna, Tash, Cameron, Brinky, Elena, David, Claire, Rich, Box, Sezgi, Becky, Sam, Thomas, Harry, Ron, Hermione, and countless others: you have saved me from the pit of despair. Lastly, I would like to thank my partner Urs for his impressive composure in the face of my increasing cantankerousness, for all the pesto he provided me with, and for letting me take over the dining table for the last five months. Thank you, and I’m sorry about all the crumbs.

“But then it occurred to him that any progress he had made on his quest so far he had made by accepting the help that had been offered to him”

Neil Gaiman, *Stardust*

Abstract

Tracing Tradition: patterns of technological innovation and the circulation of copper in Southwest Asia from the 8th to 1st millennia BCE

The regions of Southwest Asia during the Late Chalcolithic and Bronze Age were inextricably linked through trade and culture expansion, but also in their technological development. This thesis presents the results of a large-scale synthesis of published chemical data from the region from the beginning of the use of metal in the 8th millennium BCE to the start of the Iron Age in the early 1st millennium BCE. Change and continuity in alloying tradition, copper-composition, and human interaction with the material are analysed by the application of two 'Oxford System' methodologies and Kuijpers' Perceptive Categories. The resultant patterns in the copper-base assemblage are visible across space and time, and it is the aim of this thesis to marry these alterations in approach or access to material with the wider archaeological context. This large-scale approach has also drawn out aspects of technology which have, until now, generally been regarded as isolated and sporadic regional finds. A pan-regional approach has revealed they are in fact part of wider phenomena. The study of these outliers opens up the prospect for deeper insight into human interaction with and technological approach to material throughout the development of ancient metallurgy.

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DPhil in Archaeological Science
Trinity Term 2018
Word Count: 73, 273

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Chapter One: Introduction

If the recent BBC production of Poldark has taught us anything, it is that interest in copper and tin, and even the arduous process of mining, are as deeply fascinating to the general public as they are to archaeologists (though sadly we must do without romance, intrigue, family-feuds, and scythe-wielding in academic discourse). Ancient metallurgy is compelling for many reasons: the juxtaposition of industrial organisation and exquisite artisanship; the enigmatic extravagance of hoards and burials in which material wealth was so purposefully expended; the opportunity to glimpse how far people were willing to go for a desirable object before online shopping was an option! From a more conceptual perspective metallurgy has provided the temporal framework for our understanding of prehistory for almost two hundred years. Its origins and assumed pattern of development defining a pathway of exponential social and technological change culminating in modern (usually Western) society.

Although the discipline of archaeological science has moved beyond such well-worn generalizations and unilinear models of progress, the study of metallurgy, metals, and metalworking have remained a rich seam of research. Close investigation of the metallurgical data has offered a wealth of new insights into local technical traditions, yet, such research only rarely transgresses the

geographical, political, and disciplinary boundaries that divide our world. Broader studies, in which the data continue to serve as a central source about the changing character of trade and the shape of inter-regional communication, tend to subsume variation, remaining firmly seated within the economic sphere. The challenge of effectively bridging these scales is significant but offers the potential for more humanised discussions of the processes of innovation and change, in which economic trends can be explored with reference to local and regional patterns of development, the shifting fashions in ancient societies, and the roles of craftspeople and human curiosity in the manipulation of the material world. This is the challenge that this thesis sets out to meet.

The subcontinent of Southwest Asia, a hotbed of technological development from the Neolithic onwards, is a natural focus for such a study. It covers the areas of Anatolia and Iran where many of the earliest known uses of metal are found (Thornton 2009a; Hauptmann and Wagner 2007; Avilova 2008; Esin 1999; Craddock 2000; Chernykh 2017b). It incorporates regions famed for their metal resources, even in ancient times¹, and others, such as Mesopotamia and the Northern Caucasus, where primary metallurgy was unknown or unpractised (T. F. Potts 1993; Chernykh 1992; Chernykh 2017b). Were metal *was* produced the character of production across time and space is equally variable, ranging from the dispersed individual operations of the Southern Caucasus (Erb-Satullo *et al.* 2014; Erb-Satullo *et al.* 2017) to the highly organized centralized industries of the

¹ It is not without good reason that the Southern Caucasus (Ancient Colchis) have been linked to the mythical journeys of Jason in search of the Golden Fleece!

Southern Levant and Eastern Arabia, attested by phenomenally large slag heaps (Rothenberg 1972; Weeks 2003), and regions that simultaneously display both models of copper production, such as Cyprus (Kassianidou 1998). Many mysteries such as the location of the elusive source of tin, the date of the earliest smelting endeavours, and the extent to which objects may have been recycled and re-used have been raised, resolved, refuted, re-hashed, and resurrected over the long history of archaeometallurgical research in the area. This thesis does not represent a break in this tradition, but hopefully presents a fresh perspective on the debate by approaching Southwest Asia as a shifting network of relationships between peoples and metals from the later Neolithic to the early phases of the Iron Age.

Specifically building upon the work of Aurelie Cuénod (2013), this thesis began by assembling a near comprehensive database of published analytical data on metal artefacts from across Southwestern Asia, with the aim of applying a recently developed analytical framework, now commonly referred to as ‘the Oxford System’ (Pollard *et al.* 2018), which has been tailored to open exploration of spatial and temporal trends in the bulk chemistry of copper and copper alloy artefacts at a variety of scales (dictated primarily by the density of data). Though basic typological and contextual classifications also form part of this study, much of the detail in these areas was necessarily sacrificed in favour of a more comprehensive interpretation of copper flows and changing metallurgical (rather than stylistic) traditions. Where typology is drawn in to the discussion, it is used to investigate specific research questions emerging from the study of chemical patterns in the database, and particularly to address key issues around the perception and utilisation of material (see Chapter Seven). The benefit of reducing the typological

resolution was to enable a greater focus on a wider range of chemical categories, particularly alloy types, which have previously been discussed relatively infrequently in the literature (complex alloys of arsenic, antimony and nickel, very early tin-bronzes, zinc-rich copper, and iron-rich copper objects). Though this necessitated some departures from the standard approaches of the ‘Oxford System’—which was originally developed to deal with problems in the Western European context—it enabled us to recognize some intriguing pan-regional connections in metallurgical practice. These ideas are addressed fully in Chapter Five.

With such a large temporal and geographic scope, a comprehensive review of the precise archaeological context for each of the 9,838 objects contained within the database would be impractical. There was therefore a necessary distillation of the data into regional metallurgical traditions using inter-regional communication as a basis for the contextual framework. For a broad guide to the archaeology of Southwest Asia see *The Cambridge World Prehistory* (Renfrew and Bahn 2014) and *A History of the Ancient Near East, ca. 3000 – 323 BCE* (Van de Mieroop 2016). For closer regional contexts the *Oxford Handbook* series are invaluable: *The Oxford Handbook of Ancient Iran* (Potts 2013); *The Oxford Handbook of the Archaeology of the Levant: c. 8000-332 BCE* (Steiner and Killebrew 2013); and *The Oxford Handbook of Ancient Anatolia (10,000-323 BCE)* (Steadman and McMahon 2011). Unfortunately they do not cover events in the Caucasus, for which *The Archaeology of the Caucasus: from earliest settlements to the Iron Age* (Sagona 2017) and *The Southern Caucasus in Prehistory* (Kushnareva 1997) should be consulted.

The wider objective of this thesis has therefore been to synthesise all Southwest Asian pre-early 1st millennium BCE analytical data and ascertain to what extent each region was connected over time and how far technological discoveries and traditions were pan-regionally shared. A consequential aim was, essentially, to test the application of systematic and standardised approaches to such varied and diverse databases. The assembled analytical data is not only vast in terms of temporal, cultural, or geographical scope, but in terms of the variation in sample size, analytical technique, and past research focus. It has therefore been necessary to question if such heterogenous data be approached in such a standardised fashion. The following research aims and questions were developed in order to achieve this:

- 1) To understand technological approaches at the beginning of smelting and the inception of alloying
 - How soon after the development of smelting technology did copper-alloying begin, and was there a phase of simple oxide smelting before this advanced step took place?
 - Were these early copper alloys *deliberately* or *accidentally* manufactured?
 - How did approaches to alloying change of time, and differ between regions?
 - How far is this attributable to inter-regional communication and/or access to resources?

2) To fully consider the circulation of tin and its effect on regional tradition

- If the Kestel mine was exploited for tin, could it have supplied Southwest Asia? If not Southwest Asia, then could it have supplied tin locally?
- How was tin traded: to what extent was the economic model centrally organised, unique to certain periods, or changeable over time?

3) To recognise and appreciate the human activity and interaction with copper-base material

- How did the producers of copper-alloys perceive their material, and is that recognisable within the archaeological record?
- Are there any associations between copper composition and typological category?
- How far can we understand recycling and re-use of material through the behavioural qualities of primary material?

To realise the outlined aims and objectives it is necessary to be familiar with the conclusions and research that has come before. Chapter Two focusses on past study in four sections: past archaeometallurgical research; an appraisal of the evidence pertinent to the debate of the earliest smelting which covers the 8th to 5th

millennia BCE; an evaluation of the research into sources for Southwest Asian tin; and a synopsis of inter-regional communication from the 4th millennium to the 1st millennium BCE. The first section concerning archaeometallurgical research is presented thematically: by provenance studies, metallurgical provinces, fabrication techniques, entire metallurgical process, and experimental archaeometallurgy. Of course, projects cannot always be neatly demarcated by these themes, in which case they have been organised by the main objectives as described in the publication. It has been attempted to provide an insight into the types of research significant in the region of study by presenting extremely influential and long-term research projects alongside smaller, more site-specific studies. The consequent sections are principally summaries of two debates: indirect and direct evidence of early smelting is outlined, and past approaches to the 'tin-problem'. The latter included an extensive reassessment of the literature involving the Kestel mine. The synopsis of trade and communication across Southwest Asia is intended to provide the main archaeological framework for this research. In later chapters patterns of copper and copper-alloy use and circulation highlighted in the data are referred back to and interpreted alongside this contextual scaffold.

In Chapter Three the practicalities of the collation and pre-processing of large-scale data are reviewed, explained, and justified, with special emphasis on issues of data quality and cohesion. For example the comparability of chemical data obtained from numerous analytical techniques and across various national analytical traditions are described and it is outlined how the resulting inequalities were dealt with. In a similar vein, the difficulties in the compilation of a pan-

regional chronology is outlined, alongside description of the tests that were applied to the data in the development of the chronological framework. A full discussion of the 'Oxford System' follows, incorporating the objectives, philosophy, methodologies, and approaches behind it. The initial results are given as a series of regional profiles in Chapter Four.

Chapter Five incorporates analysis of regional alloying practice. A copper-base metal is denoted an alloy if it contains >1% of one or more of the following elements: arsenic, nickel, antimony, silver, lead, zinc, iron, and tin. Very early tin-bronzes (dated to pre-3rd millennium BCE contexts) are considered an alloy at 0.5% Sn, as opposed to >1% Sn in later periods, as the section on early tin deals with the possibility of 'accidental' or 'one-step' smelting of weathered tin-copper-ores. The pattern of alloying tradition is then studied chronologically, drawing on regional narratives: for example, accidental or deliberate alloying is discussed in relation to copper objects dating to the 4th millennium BCE; 3rd millennium tin-bronze use is addressed with regards to the Kestel mine; and the change of copper supply from Magan copper to Cypriot copper in the 2nd millennium BCE. The chapter ends with a discussion of copper-alloys not restricted to certain contextual discussions but noticeable in their wider use.

It is in Chapter Six that the 'Oxford System' for trace elements is applied to the chemical data and its efficacy assessed. After a broad application of the methodology in order to see general trends and patterns of copper flow, it is then specifically implemented in the question of how tin was traded across Southwest Asia, regardless of its provenance, and in ascertaining whether regional tin-bronze traditions were cohesive or disparate. The sixteen copper groups at this stage are

combined with tin content distributions to ascertain the likelihood of a regional tradition reflecting that of primary or secondary tin-bronze production. Though these trends tend to reflect cultural and economic cohesion or dissonance, especially with regard to tin-bronze production centres and inter-regional trade, if the locally traded or pattern of re-use can be made visible it provides knowledge of state-run vs decentralised endeavours and innovation. In turn this provides insight into the activity of regional inhabitants and craftspeople.

In Chapter Seven the behaviour and activity of people is once again the focal-point of this research, and manipulation and knowledge of material is addressed through Kuijpers' *Perceptive Categories* (2017). If it is possible to understand patterns of material-use through categories pertaining to the perceptible quality of that material and its consequence on technological or stylistic choices of the craftsman, then it is possible to begin to visualise how people interacted with that material. This particular methodology applied to human-copper interaction depends on the levels of alloying elements at perceptible quantities within the copper composition. Recognisably separate materials were produced and utilised differently. In this chapter there was a necessary down-scaling of focus, as particular typologies were studied in relation to their copper composition, and within one region. Although large-scale approaches can tell us about patterns of human interaction with material, it is necessary to look closer at specific regions as traditions may not be identical from region to region (or in fact from workshop to workshop, which is an obstacle that cannot be addressed here).

In Chapter Eight, aspects of the previous three chapters are reviewed and assessed for success or limitation within the research framework. The form this takes is to

address the research questions outlined in this chapter and discuss where the application of methodology has been appropriate and profitable, and where the answer might have been better arrived at with a different methodological approach. The main and most exciting narratives found in this body of work are highlighted and reiterated, along with suggestions of how these avenues may be further researched.

Chapter Two: Cultural Interaction and Technological Development in Ancient Southwest Asia

Given the geographical and temporal scale of this research, a comprehensive archaeological and historical review of each study region is beyond the scope of this thesis. Instead, the transformation of Southwest Asian societies will be approached from the more restricted viewpoint of metallurgical development, cultural contact and social change in order that patterns emerging from the analyses can be compared and understood within a broad framework incorporating both external and internal influences. Similarly, a regional approach to the development of each individual metallurgical tradition cannot be addressed, and as such this is conducted on a broader scale of general metallurgical developments in Southwest Asia through time.

This chapter will address the earliest evidence of smelting technology in Southwest Asia and attempt to define a basic timeline for the development of its metallurgical traditions. It will focus upon the lively discussion of tin sources in Southwest Asia, and the long debate which surrounds the Kestel mine and Göltepe processing site, before a description of inter-regional trade and communication from the 4th millennium to the 1st millennium BCE is outlined. First there is an

overview of the archaeometallurgical research conducted in Southwest Asia, with focus on the largest and most influential studies from each region.

1 A zeitgeist of archaeometallurgical research in Southwest Asia

There are many facets of archaeometallurgical research, only some of which are covered in this section owing to their relevance to the overall thesis. Lead isotope analysis, though an important technique in the research of metallurgical tradition, has been largely ignored, and is only mentioned if conducted alongside chemical analysis. Even within the smaller field of chemical analysis there are factions based on aims, project scope, and analytical method (for more detail on the differing analytical methods represented in the database see Chapter Three, section 1.2.). The following presents an overview of archaeometallurgical research relevant to Southwest Asia, split into research type, mostly dictated by the loose overall aims of the project which are as follows: provenance, fabrication technique, the entire metallurgical process from mine to metal, and the inter-regional sharing of metallurgical traditions. At the end is also included a description of experimental archaeometallurgy as it pertains to analytical research. For a description of research conducted on Iranian samples prior to 2011, see Cuénod (2013).

Some archaeometallurgical studies do not fall into any of the above categories but will briefly be mentioned here and examples provided. Often, excavation seasons have an accompanying analysis of metal finds from the site. These analyses are

conducted in order to characterise metal and add to the corpus of archaeometric data, rather than with specific research aims in mind. For example, Kunç (1986) conducted chemical analyses on 44 copper-base objects from the İkiztepe excavation (Anatolia), finding that half the objects were arsenical-bronze and the other half unalloyed copper. Similarly, Lyonnet *et al.* (2008) chemically analysed five objects from Late Chalcolithic Kurgans from Soyuq Bulaq (Southern Caucasus, Azerbaijan), alongside other grave goods such as ceramics and lapis lazuli. The awl and dagger were made of arsenical-bronze, and the beads were silver-copper alloy. All alloys could have been naturally made or artificial, and local or from long-distance trade. Such projects though not conducted with an aim in mind are extremely useful for the accumulation of data and a rough idea of metal characteristics and traditions from each region.

1.1 Provenance studies

Provenance studies were perhaps the most common form of analytical research conducted on metals for several decades, but do not fall only within the scope of chemical data. Many such studies only include lead isotope analysis, and they will not be considered here unless there is also accompanying chemical data. Provenance studies focus most specifically on the origin of the metal, though this is usually narrowed to the provenance of the ore deposit since the production-provenance may lie at a distant location from the mine - the object will obviously contain the chemical or isotopic 'fingerprint' of that source (provided no recycling or post-production processes have taken place) and not the production location. Fabrication techniques and typological analysis are more relevant to the latter.

Provenience studies are often applied to understanding of ancient trade-routes and complexity of regional contacts.

Provenience studies have been popular in understanding Anatolian metal, owing to the large number of copper deposits present in the region, and thus a local or imported ore indicates much about regional interaction. Gale *et al.* (1985) compared chemical and lead isotope data from Anatolian copper-base objects dating to the Chalcolithic and Bronze Age with potential ore sources from Anatolia and Bulgaria. They concluded that the same or a similar ore used for copper-base objects from Mersin and Troy were obtained via sea-borne trade as the signal from the Ergani Maden deposits did not match any coastal copper-base objects. Begemann *et al.* (1994) studied eighteen arsenical-bronze objects from Ilipinar in Anatolia, also with lead isotope and chemical analyses. Though the question of metalworkers' intentionality of improving the behavioural properties by addition of arsenic is mentioned, the aim was predominantly to ascertain where the ore or material originated. As the contemporary copper-base objects from Serbia and Bulgaria were low in arsenic the Ilipinar assemblage was deemed not to originate there, and the conclusion was that Chalcolithic Ilipinar was not greatly involved in long distance trade. Begemann *et al.* (2003) also carried out similar studies on twenty-two objects from Besiktepe, the lead isotope data of which indicated Anatolian ore sources, but with inconclusive chemical data.

Knapp and Cherry (1994) conducted similar research, although the focus was on the entire metallurgical products in the manufacturing process. Cypriot ores and objects, as well as local clays, pottery, and various other production debris, were analysed chemically and isotopically. The aim of this work was to present a

cultural case study on provenance work, attempting to define a characteristic Cypriot copper signal while utilising the favourable situation of the relative isolation of Cyprus as an island with its own copper deposits. The alteration of the chemical and isotopic signal through the production process was also studied to better understand how copper signals may relate to their ores over time.

Though the research on artefacts from EB to IA Pella (Southern Levant) was overtly a multi-disciplinary study focussed on a large body of data from one site to effectively chart the chronology of metallurgical development, the conclusions are mostly based on provenance of material (Philip *et al.* 2003). The unalloyed copper signal matches that from Faynan, whereas the arsenical-coppers were potentially related to Cyprus or Anatolia, suggesting complex resource acquisition. There was also much evidence of recycling, both of 3rd millennium copper objects and 2nd millennium tin-bronzes. The fabrication techniques mentioned were considered 'low-tech', owing to the paucity of casting techniques. Similarly, copper-base objects from MB Sidon (Southern Levant, Lebanon) were chemically and isotopically analysed (Le Roux *et al.* 2003). The conclusion, based upon the lead isotope signature, was that there was trade in metals between the regions of the Eastern Mediterranean.

Begemann *et al.* (2010) conducted a study firstly to establish the chemical and isotopic signature of Omani copper, and secondly to ascertain what proportion of the Mesopotamian assemblage was made of this copper. Arsenic and nickel are shown to be positively correlated in Omani ores and artefacts, however only two thirds of copper in Mesopotamia has such a signal. They also established that there are some artefacts which match both the Omani copper chemical signature and

isotope range dating to the end of the 4th millennium BCE, though there is no evidence of copper production in Oman at this time.

Middle Bronze Age weapons from Byblos and Tell Arqa in Lebanon were subjected to lead isotope and chemical analyses by El Morr *et al.* (2013). This research was predominantly occupied with provenance, though aspects of fabrication technique were also studied. Lead isotope and trace element signatures were compared with object and ore signatures from Iran, Egypt, Faynan, Cyprus, Greece and the Aegean, Saudi Arabia, Timna, Anatolia, Oman, and the UAE, and results suggested links with Egypt, Oman, and Iran. The correlation between certain object types, alloys, and manufacturing techniques indicated the choices of craftspeople and therefore that their knowledge was developed, sophisticated, and complex.

A study of twenty seven ingots from the Levant by Yahalom-Mack *et al.* (2014) was aimed at revealing information about ores and smelting procedures between the 2nd millennium and 1st millennium BCE. The results were then compared with ore compositions from Cyprus, Turkey, Arabeh, and Sinai. It was concluded that the Levant was supplied with copper from Cypriot and Arabeh ore sources, but that the supply fluctuated over time.

Hasanova's studies from (2015) and (2016) are concerned with the chemical analysis of spearheads and arrowheads from MB Southern Caucasus (Azerbaijan). In both articles a local copper source is suggested, and that tin was imported from Anatolia (Kestel), Iran (Deh Hosein), or West Afghanistan via Mesopotamia. The addition of lead to improve the mechanical properties of low-tin-bronze is theorised as an economising endeavour owing to the cost of tin, as there are many

local lead ore deposits. The provenance of tin, though widely discussed and sought, is rarely attempted via provenancing studies of tin-bronze alloy owing to the confusion of the signal from copper. However relatively recently archaeologists have begun to focus on the question of tin-isotopes and their ability to indicate potential tin sources or provenance tin-bronzes (Nowell *et al.* 2002; Stos-Gale and Gale 2009; Hausten *et al.* 2010; Balliana *et al.* 2013; Brüggmann *et al.* 2017).

1.2 *Fabrication and production techniques*

Caneva and Palmieri (1983) chemically analysed swords, daggers, and some needles from Late Chalcolithic Arslantepe in order to find information about smelting techniques. They found that arsenic concentrations varied notably within each individual object as “selective dispersion appears to be linked to the different phases of the smelting process” (*ibid.* p. 638). The part of the object which cooled quickest had lower arsenic quantities, and it was therefore easy to distinguish between objects made in open moulds and closed moulds, as the former had lower arsenic concentrations at the surface on one side of the object. In the course of the research they also found that sulphide ores were in use at Arslantepe, and complex smelting techniques were in use by the Late Chalcolithic.

Seven ingots from the Southern Levant were analysed by Maddin and Stech-Wheeler (1976). It was found that these objects were made from weathered, not roasted, ore, and had had a flux added during the manufacturing process. It was also discovered that the ingots were secondary castings which had not been exposed to oxygen during re-melting. It was not known if the secondary castings

were from larger primary ingots broken into smaller ingots, or from the re-melting of scrap copper: however it indicated the process of ingot manufacture in the region during the Middle Bronze Age.

Balthazar (1990) set out to readdress the balance of research focus on Cypriot copper-base materials as previous work was weighted towards the Late Cypriot Period. She maintained that the Early and Middle Cypriot Periods were the formative years of copper technology on the island. The aim was to re-examine the corpus of previously analysed objects, re-assess stylistic preferences by time, and finally address the copper objects belonging to each period as a whole to identify changes over time. This would therefore help to define the options that were available to ancient metalsmiths, and what economic, social, and technological factors might have determined those choices.

A number of rings and bracelets, vessels/sheet metal, and pins and awls from occupational levels at Tell Abraq (Eastern Arabia, U.A.E) were chemically analysed and metallographically investigated by Weeks (1997). The aim was to better understand metallurgical practices at the site and how they fit into the wider context of Eastern Arabia. The tin content of the rings, which were mostly not cold-hammered, was above the level required for better casting properties, and so he concludes that the tin added was intended for aesthetic purposes. This was further supported by the relative lack of tin in pins and awls. It was also noted that the number of tin-bronzes in Umm an-Nar and Wadi Suq phases was unusually high in comparison to the rest of the wider region, perhaps owing to the site's coastal location on the Persian Gulf.

De Ryck *et al.* (2003) studied the microstructure and chemical composition of forty-six objects from Tell Beydar in Northern Mesopotamia, focussing mainly on alloying tradition– mainly arsenic and tin contents - rather than determining ore type in use. By studying alloying element quantities they were able to ascertain that copper at this site had a clear chronological sequence in the use of arsenical-bronze, that the adoption of tin-bronze occurred c. 2600 BCE, and that the overall pattern of copper alloy use fitted into the wider tradition of Southern Mesopotamia. It was also discovered that the same metalworking techniques were applied regardless of alloy type, but that the technical expertise and control developed over time.

Chemical and lead isotope analyses were carried out on metal objects from Late Chalcolithic and Early Bronze Age Arslantepe and although there was some interest in the provenance of the arsenical-bronzes (suggested as the Southern Caucasus), most objectives were aimed at understanding manufacturing process (Palmieri *et al.* 2002). Significant similarities in organisation and alloying-patterns were noticed between Arslantepe and the Southern Levant. The results from lead isotope analysis established that the copper-silver alloys were fabricated by deliberate mixing of two metals, and therefore present the earliest evidence of intentional alloying. There was also evidence of surface enrichment/depletion gilding. The suggestion of ores imported from the Southern Caucasus and the possible presence of objects made from local ores led to the suggestion of a two-tier trade system: one of goods exchanged on the market, and the other a high-status, elite gift-exchange.

Meliksetian and Pernicka (2010) compared the chemical compositions of high arsenic objects from Gegharot (EBA) and Lori Berd (LBA) in order to understand the process behind the alloy composition. There were three types of alloy used for typologically specific bead types, one group of which contained unusually high arsenic. The microstructure of these was compared to three objects from Lori Berd. The findings indicated that the arsenic rich objects had not been surface enriched, and that craftspeople must have been using an advanced smelting technology to produce such alloys.

Fifty-seven weapons from Byblos were metallographically and chemically analysed by El Morr and Pernot (2011) with the aim of understanding regional fabrication processes of the Southern Levant. They found that there was widespread use of arsenic and tin as alloying elements, with no visible preference for tin over arsenic, though perhaps an emphasis on tin for high status weaponry. It was also suggested that brazing techniques may have been imported to Byblos either from Mesopotamia or Egypt, and finally they concluded that craftspeople may not have added lead specifically to improve castability but as an economy. A similar study by El Morr and Mödlinger (2014) found that there were no clear variations in forming techniques or alloying compositions across the region of the Southern Levant, suggesting a shared metallurgical tradition, possibly even with the same processes of metal refinement.

In a different type of study that was still generally concerned with fabrication techniques, Geniş and Zimmerman (2014) chemically analysed forty-five objects from an EBA grave-site at Kalinkaya, near Alaca Höyük. The aim of this research was to focus on small, rural approaches to the manufacturing processes, rather

than those at high-status settlements. The objects analysed were mostly simple jewellery, and faults generated during the production process were not repaired, either owing to lack of skill or because the artefact was unfinished. Tin was not present in the objects before the early 2nd millennium BCE, and recycling of metal appears to have been very likely.

Oudbashi and Davami (2014) studied twenty-two copper-base vessels from 10th to 7th c. BCE Sangtarashan (east Luristan, Iran). They found that the copper was smelted using sulphide ores, that tin was added using uncontrolled procedures (co-smelting or cementation), and that the sheet metal was produced through a cycle of cold working and annealing. Previously Oudbashi *et al.* (2012) had analysed ten metal pieces from Haft Tappeh and compared them with ten segments of vessel from Sangarashtan (possibly some of the same objects as in 2014). They found that the two sites had different approaches to alloying (Cu, CuPb, and CuSnPb at Haft Tappeh, and Cu and CuSn at Sangarashan), but similar approaches to the material and use of sulphidic ores.

Massa *et al.* (2017) analysed objects from Demircihüyük and reassessed regional mining evidence. The aim was to understand use of different alloys and different fabrication techniques, though there was some interest in provenance, which is planned for a further study. They found that >2-3% As was indicative of intentional selection of arsenic-rich ores or addition of arsenic, and that open mould, bivalve, and lost-wax casting were all in use at the site, suggesting skilled specialists using complex techniques, even for relatively simple object types.

1.3 *The entire metallurgical process*

Selimkhanov (1962) outlined past and ongoing research in the USSR of systematic chemical investigations on objects relating to the entire metallurgical process (metal artefacts, ore, slag, crucibles, and moulds) though the dating of many of the contexts were not well known. The aims of the additional research presented in the paper were to characterise the alloys in use during the early stages of metallurgy in the Southern Caucasus, use chemical composition to understand regional tradition, ascertain the deliberation behind alloying, understand which ores were chosen, and to attempt to date many of the less securely dated objects.

Leese *et al.* (1984) conducted a large-scale study of ores and metal objects from the smelting site at Timna (Southern Levant, Israel). It is worth pointing out that this was attempted with the aim of improving provenance studies, as it was the changes from ore to metal, via fluxes and impurities, etc., which were documented. The effect of these processes was then assessed in terms of how to characterise or predict certain chemical signals. They found that there was not much overall change in composition but thought it likely that this was owing to the homogeneity of samples.

In the late 1990s a smelting site on Cyprus which was vastly different to previously studied mining sites was uncovered and the mining and smelting processes were identified by Kassianidou (1998), therefore presenting a pivotal moment in Cypriot archaeometallurgical research. Until this point Cypriot mining and smelting endeavours were seen only as large-scale, centrally organised affairs, with copper production primarily centred on export in long-distance trade networks. The small site of Almyras, on the other hand, only produced one tonne of

copper, and was therefore not a production centre on the same scale – indicating that there were parallel mining industries in prehistoric Cyprus.

An assemblage of ores, slags, crucibles, unprocessed copper, and copper-base artefacts from Chalcolithic Shiqmim (Southern Levant, Israel) were analysed in order to understand the metallurgical tradition which took place at this site (Golden *et al.* 2001). There is some discussion about the provenance of the ore in use as there are no ore sources situated near the site, though Faynan is indicated as the most likely source owing to relative proximity. There appears to have been no evidence of fluxing during the smelting process as the slag present seems to have been accidental (considered as such because it contains such large quantities of copper). The excavators also discovered a ‘proto-furnace’ at the site alongside crucibles. The metal produced contained very high quantities of arsenic, antimony, and silver, similar to the Nahal Mishmar hoard, suggesting shared metallurgical tradition. However pure copper and complex copper clearly belonged to two separate industries.

Long-term work on the Faynan mining district, based on fieldwork from 1983 to 1993, was presented by (Hauptmann 2007; Hauptmann *et al.* 1992). The aim of this research was to investigate the production process by conducting mineralogical, chemical, and isotope analyses on samples of ore, slag, and metal to ascertain the effects of smelting, melting and processing on the material. In a connected study (Hauptmann *et al.* 1999) analysed the lead isotopes and trace element contents of twenty one objects from EB Arad and three from Sinai to indicate that the provenance of the copper in use was either Faynan or Timna. They were also able to prove that the addition of arsenic in a number of those

objects was accidental rather than intentional. In a similar study (Hauptmann *et al.* 2015) analysed the trace elements of crescent-shaped ingots from Early Bronze Age Southern Levant, and found their compositions to be almost identical to the Faynan copper district.

Courcier *et al.* (2012) set out to characterise the metallurgical processes occurring at Chalcolithic Mentesh-Tepe in the Southern Caucasus (Azerbaijan) in order to understand the development of metallurgical technology in the region. As well as finished artefacts they analysed prills, ore fragments, semi-smelted ore, and crucible fragments. Through these analyses they documented the metallurgical process which occurred onsite, from the crushing of local ores, to the potential fabrication of ingots.

Kashani *et al.* (2013) chemically analysed four copper objects and one slag sample from Late Chalcolithic Meymanatabad (Tehran region, Iran). The objective was to characterise the material and better understand the mineralogy of the ores. They found that local work revolved around smelting arsenical-coppers but concluded that the addition of arsenic was an intentional secondary process as there was none to be found in the slag sample.

1.4 *Metallurgical Provinces/spheres of influence*

Chernykh's introduction and development of metallurgical provinces began in the 1960s and has spanned several decades since. Through large-scale chemical analyses of metal objects he studied forms of standardisation in technique and alloy-choice and was able to characterise *metallurgical foci* of shared technological

tradition bridging many different cultures. *Metallurgical provinces*, containing related *metallurgical foci*, encompass very large geographical areas, and many cultures and can last for two to three thousand years (Černyh *et al.* 1991; Chernykh 2011; Chernykh 1992; Chernykh 2017a; Chernykh 2017b). This research paved the way for understanding regional variations and similarities in technological choice, production, and consumption.

In a small-scale version of archaeometallurgical research spanning an area containing many cultures, Hughes *et al.* (1981) published preliminary chemical data on a selection of Urartian tin-bronzes from the 9th to 7th c. BCE, indicating a similarity in composition between Assyrian and Urartian copper-base objects, including the level of tin. They also indicate similarities with contemporaneous Greek statuettes which show similarities in composition.

Thirteen Syro-Palestinian weapons dating from EB to MBI were chemically analysed by Philip (1991). What was predominantly noticed was regional difference in alloy use between the northern region and the south. Owing to the relatively small distances between these regions Philip theorised that lack of access to tin could not have been the main reason for a lack of tin-bronze use in the south, but rather technological conservatism, also visible in typological forms and ceramics, was responsible. The two regions within the Southern Levant, therefore, were perhaps part of two separate regional traditions.

Shalev and Northover (1993) re-analysed several objects from the Nahal Mishmar Hoard in order to fit the spectacular finds into the regional context. Since the original analysis of these objects, similar objects from neighbouring sites had been discovered and analysed. It was found that the extraordinary complex-alloys of

Nahal Mishmar matched similar prestige objects in the region, suggesting a regional metallurgical tradition of high arsenic and high antimony copper.

Within the framework of previous research conducted with Chernykh on *metallurgical provinces*, Avilova (2008) collated a database of copper-base objects from Mesopotamia, Iran, Anatolia, and the Levant due to their close economic and cultural connections. The information gathered covered many aspects including fabrication techniques, object type and function, and the chemical data if it was available. The conclusion was that the entire region, though with the Levant slightly towards the outskirts, showed a “single tradition of production”, with northwest Anatolia and Mesopotamia displaying the greatest degree of similarity (Avilova 2008).

1.5 Experimental archaeometallurgy

The overriding aim of experimental archaeometallurgy is to challenge assumptions about materials which are frequently discussed and to better understand the techniques available to ancient craftspeople. Experimental and reconstructive smelting research went through something of a zenith in the 1980s and 90s, mainly regarding ore types, temperatures, and sulphide smelting, whereas casting experiments were more popular in the early 2000s (Doonan and Dungworth 2013). The following examples of research are concerned with experimental smelting as they are most relevant to this thesis.

Rostoker (1975) believed the multi-stage process of copper production from chalcopyrite to be too complex for the discovery of use of sulphide ores. Through

experimentation it was discovered that chalcopyrite could be smelted into copper in a two-stage process that required roasting of powdered ore, then reaching temperatures of 1300° C, though this is considered unachievable for ancient smelters. Later experiments were then put forward of a one-step, 'co-smelting' procedure of mixed oxide and sulphide ores, which successfully produced metallic copper at c. 1250° C (Rostoker *et al.* 1989; Rostoker and Dvorak 1991).

Two similar influential studies were undertaken by Lechtman (1996) and Lechtman and Klein (1999), which will be discussed here though principally they relate to Andean metalwork. In her 1996 paper, Lechtman set out to test the mechanical properties of arsenical-bronze and tin-bronze, as the superiority of tin-bronze (its hardness, ductility, malleability, etc.) was frequently used as an explanation for the replacement of arsenic as the dominant copper alloying element. It was found that arsenical-copper, even when arsenic is present in low concentrations, is as desirable an alloying element as tin-bronze. In Lechtman and Klein (1999), accidental versus deliberate smelting of arsenical-bronze was tested by conducting co-smelting experiments between copper oxide and copper/iron sulfarsnide in varying concentrations. It was ascertained that neither roasting, nor a two-step process was necessary to produce arsenical-bronze, and that it could be produced successfully with a range of ratios between oxide and sulfarsnide.

Earl and Özbal (1996) conducted smelting experiments from samples at Göltepe so as to ascertain the possibility of producing tin from Kestel. Cassiterite powders were vanned and subjected a smelting process with fine charcoal and potassium/sodium flux added to a crucible-type furnace, successfully producing beads of tin. Three stages of vanning were necessary to separate the cassiterite

from gangue, and the results were concluded to prove tin-mining from Early Bronze Age Kestel.

More recent experimental research has focussed on the ability to co-smelt copper and tin minerals in a single step process. Rovira *et al.* (2009) crushed a polymetallic copper ore (containing bismuth, arsenic, tin, and lead) and cassiterite in a crucible, which was then added to a simple open furnace heated with charcoal and fired with bellows to c. 1200° C. The resultant prills varied in colour from red copper to light-grey tin. These prills were chemically analysed and then melted to produce an ingot weighing 53g. The chemical analysis of this ingot showed that it contained 15% Sn, therefore proving that it was possible to easily attain a copper-tin alloy through direct co-smelting of copper and tin ores. More recently experiments have been used to produce copper-arsenic-tin alloys of varying compositions in order to display the full range of possible colours produced (Radivojević *et al.* 2018).

2 The development of metallurgy

2.1 *Malachite and native copper*

Malachite was well known in many regions of Southwest Asia long before metallurgical processes were developed. From the 11th to the 9th millennia BCE we see its use in many Neolithic sites (alongside the use of other copper minerals) in symbolic settings (Kienlin 2014, p.449), as beads, or used as pigments (Roberts *et al.* 2009, p.1313; Killick 2014, p.19; Kienlin 2014, p.449; Radivojević *et al.* 2010,

p.2777). 'Greenstones' are often mentioned in the discussion of early metallurgy, due to the fact that often where malachite is found so is native copper, suggesting a link between the collection of the stones and the discovery of copper in metallic form (Charles 1985, p.23). The regions and sites which have produced large numbers of malachite beads have also produced small artefacts of native copper. At Çayönü Tepesi, for example, there are numerous examples (over 4000) of malachite, some worked into objects, as well as over a hundred native copper artefacts dating to the 8th millennium BCE (Hauptmann and Wagner 2007, p.67; Avilova 2008, p.76; Craddock 2000, p.152; Roberts *et al.* 2009, p.1013; Chernykh 2017b). Forty-five similar copper objects come from Aşliki Höyük, dated to the 8th millennium BCE (Esin 1999, p.19; Chernykh 2017b).

The first known native copper object, a bead, found in Iran appears slightly later from a late 8th/early 7th millennium BCE context, and its presence has been linked to the obsidian trade from the Anatolian highlands (Thornton 2009b, p.308; Thornton 2014, p.672). Native copper use never occurs in the Southern Levant, however, despite the common use of malachite as 'greenstones' and obsidian trade connections with Anatolia (Golden 2009; Chernykh 2017b). Similarly, Egypt uses malachite for pigments and cosmetics in the 5th millennium BCE, but launches into a fully-fledged metallurgical industry in the 4th millennium BCE skipping the use of native copper (Killick 2014, p.510).

It is questioned whether native copper use is an extension of lithic technology rather than an advancement toward metallurgy proper (Maddin *et al.* 1980, p.211). There is evidence of heat treating of carnelian beads at Harappa, which were then traded to Eastern Arabia (Kenoyer 2005). However heat treatment does not

appear to have been applied to Armenian carnelian (Brunet 2009). Flint blades from Anatolia and the Mediterranean regions are also documented as having been heat treated during production (Maeda 2017; Pelegrin 2012). Therefore there was a definite tradition of hot-working before the advent of metallurgy, but the fact that native coppers are believed to have been deliberately melted down would represent a step towards a new technology (Craddock 2000).

Melting and casting native copper removes the distinctive microstructure within the copper body, thereby making it metallographically indistinguishable from smelted copper (Craddock 2000). Some scholars argue that native copper can be distinguished by its lack of impurities, however the native copper objects from Anatolia often contain significant quantities of arsenic (Özdoğan and Özdoğan 1999; Maddin *et al.* 1980). These high arsenic coppers are therefore either very early evidence of smelting, or proof that native copper cannot be easily distinguished by its chemical purity alone.

2.2 Development of smelting technology

The search for the beginning of smelting technology is a highly debated subject and the time-span covers over two millennia. One aspect of the debate is to ascertain whether there was a single invention of smelting in one region, from which it spread, or whether there were multiple regions of technological origin (Kienlin 2014, p.448; Roberts *et al.* 2009, p.1014). Others argue for 'stimulus diffusion' in which the technology itself does not spread, but awareness of the concept or its finished products does, prompting local experimentation and independent

development (Frame 2009, p.41). Weeks (2013, p.285) goes further in describing this as “synchronous technological development”, in which external influences affect many regions contemporaneously as culture exchange intensifies influencing approaches to technological processes, for example during the Uruk period, rather than technological transfer from person to person, which would require many contact hours. Unfortunately the dating of many potential early smelting endeavours is shaky and debated. Until knowledge of early smelting is more firmly established, it will surely be impossible to pinpoint how or where it came into being.

A key problem in establishing the earliest smelting technology is how to recognise the by-products and waste of a smelt. There is much question over how much slag was produced in the earliest smelts, though ‘slagless’ smelting is not generally accepted as a theory (Doonan 1994, p.96; Killick 2014, p.37; Pernicka 2014, p.253). It is quite easy to replicate when production remains at a small scale both with and without a crucible. Then the question of whether slag is reliably recognised by archaeologists, as often it must have been crushed to release the prills produced. Are the experimental stages of any endeavour recognisable, as experimental workings do not produce established, recognisable equipment? The earliest metal technology would surely have taken place in domestic settings, with domestic rather than specialised equipment, and on such a small-scale that the evidence would not necessarily appear out of the ordinary to the archaeologist. It might be possible to determine the first concerted effort to produce metal in a consistent manner, but this itself would not represent the very start of the technology.

Smelting is generally agreed to have been developed on a wide scale at least by the mid-5th millennium BCE - it has certainly by this time begun to appear fully-fledged in the Southern Levant (Golden 2014, p.562), the Caucasus (Courcier 2014), Iran (Weeks 2013), Egypt (Killick 2014), and in the Carpatho-Balkan region (Chernykh 2017b). 5th millennium Anatolian copper objects, such as axes and chisels, from Değirmentepe and Mersin are believed to have been made of smelted copper, though there is no associated metallurgical debris (Lehner and Yener 2014, p.539).

The impurities in many copper objects from the 5th millennium BCE across the whole of Southwest Asia also suggest a widespread adoption of smelting technology (Thornton 2014, p.675), regardless of evidence in each specific region. Many scholars (Kienlin 2014; Radivojević and Rehren 2016; Radivojević *et al.* 2010) argue for the Balkans as the birthplace of smelting technology. The site of Belovode in Serbia, dated to the 5th millennium BCE, provides the “earliest documented proof of pyrometallurgical extraction” (Radivojević *et al.* 2010, p.2787). This Vinča culture site has produced vitrified slag, green-stained ceramics and metal droplets dating from between 5000 and 4500 BCE; the earliest slag found at the site is dated to 5000BCE (*ibid.* p.2779). This is the earliest and most securely dated example of smelting operations in the archaeological record, though there are some less securely dated potential examples from pre-5th millennium BCE contexts.

There is potential evidence of early smelting from Tal-I Iblis in Southeastern Iran, where hundreds of smelting crucibles were found dating to periods I and II (Frame 2009, p.23; Weeks 2013, p.278). Unfortunately the dating of these finds appears to

be a point of contention. The earliest levels of Tal-I Iblis are referred to as late 6th millennium (Hauptmann 2014, p.92; Craddock 2000, p.152; Roberts *et al.* 2009, p.1014; Thornton 2014, p.675), early 5th millennium (Weeks 2013, p.278) or both (Frame 2009, p.23; Thornton *et al.* 2009, p.308). The confusion over the date does not detract from the importance of the finds of early smelting, but a fixed chronology would help distinguish between its legitimacy as the earliest concrete evidence of smelting or place it as contemporaneous with the early evidence of smelting in the Balkans.

There is also the evidence of artefacts themselves to be considered, which might be considered *indirect* evidence of smelting technology. A tin-bronze pin, possibly dating to the 7th millennium BCE, was found 48km northwest in Konya (database number: 3366). This can only have been smelted due to the presence of tin in the chemical composition, as native tin-bronzes do not occur. Native copper may have been melted with native tin, in which case it is a pre-smelting technology alloy: but there are no examples of metallic tin until 1200 BCE, which makes this unlikely when considered with the lack of supporting evidence to date (Maddin *et al.* 1977). It is possible that tin ore was added to melted native copper, however this would surely represent the beginnings of smelting technology as it would involve the recognition that the tin stone could be transformed in some way into metal. The awl from Tel Tsaf was completely corroded, but reportedly contained 6.6% Sn (Garfinkel *et al.* 2014a). Even if the levels of tin were overestimated due to corrosion, this still indicates its presence at levels beyond anything expected for a native copper. Another example is that of a ring from Aruchlo I in Georgia, also dated to the 6th millennium BC, which contains 8% Sn (*ibid.* p.4).

Obviously, the dating of these objects is pivotal if they are to be regarded as a potential starting point of smelting technology, and they must therefore be secure. The 7th millennium BCE pin has no further information, so must be treated cautiously. Garfinkel *et al.* (2014b, p.4) state that the stratigraphic contexts for 6th millennium BCE tin-bronze objects are secure as the chances of mixed deposits are slim, as neither site has any later layers to which these objects could have belonged. The earliest potential *direct* evidence of smelting is yet still more contentious; the much debated lump of 'slag' from 7th millennium Çatalhöyük in Anatolia (Kaptan 1990, p.75; Maddin *et al.* 1999, p.101; Roberts *et al.* 2009, p.1013). This 'slag' was not found with accompanying metallurgical artefacts and is believed by some to rather have been an accidental slag from a ceremonial artefact in a burnt burial (Radivojević *et al.* 2017, p.101).

These pieces of evidence are far too unreliable to provide a firm base for the beginnings of widespread smelting technology, but they do open up the possibility that smelting began earlier than the operational-level evidence we see in the 5th millennium BCE, and possibly in the 6th millennium. As mentioned earlier, experimental phases of technology might rely on domestic or unspecialised artefacts, and therefore the production remains would not be present in such numbers as in Tal-I Iblis or Belovode from the inception of a new technology, but the lack of these artefacts would not necessary exclude the possibility of early development of technology.

Despite the possibility of an earlier date, Iran and Anatolia appear to have been smelting copper from at least the mid-5th millennium BCE and it had become a widespread practice by the 4th millennium BCE, developing to the point of

working with reusable furnaces rather than crucibles by the mid-4th millennium BCE (Weeks 2013, p.282). Smelting appears in the Southern Levant in the mid-5th millennium, with no sign of diffusion from Iran or Anatolia (Golden 2014, p.562).

The smelting tradition in the Southern Caucasus was underway by the late 5th millennium BCE, with intensive metallurgical activity taking place at Mentesh-Tepe, which included crushing of local ore at the site, smelting processes that produced slag, and the formation of the resultant copper into ingots, awls, and rings (Courcier *et al.* 2012). However there are earlier indications of smelting technology; a slag cake found at mid-6th millennium BCE Göytepe; a piece of copper ore discovered in late 6th millennium Aratashen; and several awls and rings dating to late 6th/ early 5th millennium BCE contexts at Alazani, Tsiteli-Gorebi, Kviriastskali, and Chalagan Tepe (Courcier *et al.* 2012; Kiguradze 2000). By the Kura-Araxes period there is plenty of evidence of smelting and metalworking across the Caucasus, often in domestic settings (Palumbi 2016, p.23). The evidence includes ingot moulds as well as tuyères (Courcier 2014, p.85). Though vast numbers of metal artefacts were accumulated in the Maikop Culture of the Northern Caucasus in the 4th millennium BCE (over 1500 bronze objects, 7500 gold objects, and 1100 silver objects despite evidence of frequent modern looting), there is no evidence of metallurgical technology or its associated artefacts in the region, and the artefacts are presumed to have been imported from the south (Chernykh 2017a; Chernykh 2017a; Palumbi 2016).

The drive for copper is often seen as a motivating factor behind the Uruk Expansion in the late 4th millennium BCE, but smelting processes did not appear to take place within the alluvial plains (Matthews and Fazeli 2005). Instead the

highland regions which were in contact with Uruk Mesopotamia reveal evidence of intense metallurgical processes, from mining at nearby deposits to forming ingots for trade, for example at Ghabristan, Arisman, Tal-I Iblis, and Değirmentepe (*ibid.*). However, in more recent years evidence of the smelting process, in the form of ore and crucible, have been found at Uruk colonies such as Hacinebi Tepe and Tell Sheikh Hassan, and evidence of ore processing has even been found at Warka (Algaze 2009; Özbal *et al.* 1999).

Though evidence of smelting operations does not appear in Eastern Arabia until the late 4th/early 3rd millennium (Weeks 2003, p.4), there are a few isolated metal objects dating to the 5th millennium BCE, mainly along coastal sites (Begemann *et al.* 2010; Giardino 2015). Copper production in the region does not take off, however, until the later 3rd millennium when there is a dramatic expansion in production and up to 4000 tonnes of slag are recorded at individual smelting sites (Weeks 2003, p.24).

2.3 Alloying practice

The next questions to consider are at what date, once ancient metallurgists had begun smelting copper ore into copper, the practice of alloying with other metals began; and secondly whether this was done deliberately or by accident. Previously in archaeometallurgical studies, people assumed a somewhat linear progression from native copper, to smelting simple copper-ores such as malachite, to forming arsenical-bronze by smelting sulphides, and eventually replacing arsenic as an alloying element with tin. This linear progression is not as widely adhered to in

recent decades (Doonan and Dungworth 2013; Roberts *et al.* 2009). Copper-alloys are now recognised in the archaeological record from a much earlier date, for example the phase of experimentation recognised in early Caucasian metallurgy (Palumbi 2016, p.23), and though the earliest date of smelting complex sulphides is still debated it is now recognised that it is possible to smelt copper-alloys, even copper-tin alloys, in one step from the right ore or from the right mixture of minerals (Roberts *et al.* 2009, p.1017; Pigott 1999, p.87; Heeb and Ottaway 2014, p.170; Rovira *et al.* 2009).

The most famous early alloys are sure to be those from the Southern Levant dating to the early 4th millennium BCE, mainly those from the Nahal Mishmar hoard, but also Shiqmim and other sites in Chalcolithic Palestine (Levy and Shalev 1989). The copper used for these highly ornate objects appears to have been imported into the region, though the objects themselves were manufactured locally, which is shown by the composition of sand used for the object mould (Golden 2014, p.570). When the intentionality behind alloying practice is discussed in the literature, the main elemental compositions brought to mind are those of copper containing 2 – 3% arsenic. The presence of 22.5% antimony in one of the Nahal Mishmar standards (Shalev and Northover 1993, p.43) would not go unnoticed by the craftsperson, and there appears to have been a concerted effort to collect or produce such high antimony objects in the region. Many of the objects made of antimonial-bronze and arsenical-bronze were ceremonial or ornamental (Thornton *et al.* 2009, p.304), which implied an intentional choice of materials, even if deliberate enrichment of antimony was not being applied. However, it is worth noting that this proposed

divide between tools made of pure copper, and elite objects made of complex-alloys has been largely dismissed in recent years (Golden 2014, p.573).

Apart from these exceptional early complex-alloys, there is much discussion about how deliberately high-antimony or high-arsenic ores were chosen, smelted and perceived. Roberts *et al.* (2009, p.1017) consider the earliest alloy-smelting as an accidental consequence of exploiting element-rich ores in certain regions, but that once copper alloys became widespread they propose that the choice was deliberate. The regions in which metallurgical traditions seem to have developed (the Southern Caucasus, Anatolian highland and Iran) have heterogeneous and varied mineral deposits (Lehner and Yener 2014, p.530). For that reason, Thornton (2014, p.677) sees the beginning of alloying as a deliberate choice: there are mineralogically diverse regions in Iran, but there are also many pure copper ores which would not result in copper-base alloys. Since pure copper disappears at the onset of smelting he sees this a rejection of pure copper and a deliberate move towards choosing polymetallic ores.

It is certainly possible to serendipitously smelt the complex-alloys in several different ways. Firstly, weathered sulphide ores containing arsenic, such as olivenite or domeykite, can be directly smelted (Lechtman 1996, p.478) and these minerals are the blue-green colour which could be mistaken for malachite (Killick 2014, p.40). Secondly, the co-smelting of oxide and sulphide ores is a simple process and could feasibly be done accidentally as the minerals are often found together (Lechtman and Klein 1999, p.52). Thirdly, the production of iron-arsenide speiss is another method of adding arsenic to a copper-base metal, but this

represents a deliberate step, which is only very rarely evidenced in Southwest Asia from the 3rd millennium BCE onwards (Thornton *et al.* 2009).

Early copper objects often contain arsenic, antimony, lead, nickel, silver and bismuth (Rapp 2002, 156; Yener 2009, 144). The addition of even 3% arsenic would have an appreciable effect on the working properties of the copper alloy (Killick 2014, p.39). Weeks (2013, p.286) sees the early alloys as deliberate, suggesting that there is a pattern of craftspeople experimenting with a range of polymetallic ores throughout the 4th millennium BCE.

3 The 'Tin Problem'

The production of early tin-bronze (pre-3rd millennium BCE) is an example of the intentional/accidental smelting debate involving copper-base metal for which there are very limited potential ores in Southwest Asia rather than numerous possibilities, such as in the case of arsenic-rich minerals. Cassiterite is rare in Southwest Asia, as is stannite and its secondary weathered products. Deposits of stannite have been found at unspecified locations in the Caucasus (Courcier 2014) at Madenköy in the Taurus foothills and Madenbelenitepe in the Bursa province (Öztürk and Hanilçi 2009; Yener 2009), and in the Deh Hossein copper mine in Iran (Nezafati *et al.* 2006; Nezafati *et al.* 2009; Helwing 2009; Roberts *et al.* 2009), though whether they were exploited at this time remains a matter of debate. Pernicka and Wagner (Pernicka and Wagner 1992) confirm the presence of

stannite in the Bursa and Bolcardag provinces, but are of the opinion that other metals were exploited here and consider the tin deposits too small to be worth exploiting.

3.1 *The debate*

The issue of identifying the source of the Bronze Age Southwest Asian tin supply from the 3rd millennium BCE onwards has been a fraught topic of discussion for decades, with the Kestel mine in the Taurus foothills at the centre of controversy. Broadly speaking there are two camps. One posits the movement of tin supplying the whole of Southwest Asia from the east as occasionally referenced in textual sources, possibly from Afghanistan or Kazakhstan, via one or two routes – the land route across the Iranian Plateau or the sea-borne route along the Persian Gulf (Cleuziou and Berthoud 1982; Kaniuth 2010; T. F. Potts 1993; Muhly 1985; Muhly 1973; Stech and Pigott 1986; Stöllner *et al.* 2011; Weeks 1997; Weeks 2003; Kaniuth 2007). The other leans more towards the exploitation of deposits in Anatolia, the produce of which was then traded west and supplied to Southwest Asia (Yener 2000; Yalçin and Yalçin 2009, p.129; Öztürk and Hanilçi 2009; Yener *et al.* 2015).

The two are of course not mutually exclusive, though it depends what scale of trade is being discussed – the main sticking point being whether the Anatolian deposits were exploited on a small scale for local use, or on an industrial scale to be the sole provider of tin to Southwest Asia (discussed below). One theory which is not much discussed, possibly due to its later timing, is of Egypt as a potential tin

supply, trading via Palestine (Maddin *et al.* 1977). There is also the presence of tin in the Deh Hosein mine which contains evidence of ancient workings, and is believed to have been a major supplier of tin to Iran and Mesopotamia from the 3rd millennium BCE onwards (Nezafati *et al.* 2006; Nezafati *et al.* 2009).

3.2 *The Kestel mine*

One of the fiercer debates concerning sources of tin and the extent of its trade to regions in Southwest Asia is the Kestel 'tin' mine in the foothills of the Taurus Mountains. Placer deposits of cassiterite were discovered in the Kuruçay stream, 200m below a mining site containing open pits, underground tunnels, and tools. Ceramics were found dating to between the Late Chalcolithic and Byzantine Period (Yener *et al.* 1989, p.200).

Ancient mining certainly took place at this location, but it is questioned what exactly was mined, how extensively it was mined and at what period the main exploitation took place. It is regarded by some as an industrial complex (large-scale and centrally organised), with main activity occurring in the 3rd millennium BCE and aiming at collecting tin-ore which could have been processed and smelted at the nearby site of Göltepe before being supplied to the rest of Southwest Asia (Yener *et al.* 1989; Yener and Vandiver 1993; Earl and Özbal 1996; Laughlin and Todd 2000; Willies 1992; Willies 1995; Yener 1993; Yener 1994; Yener 2000).

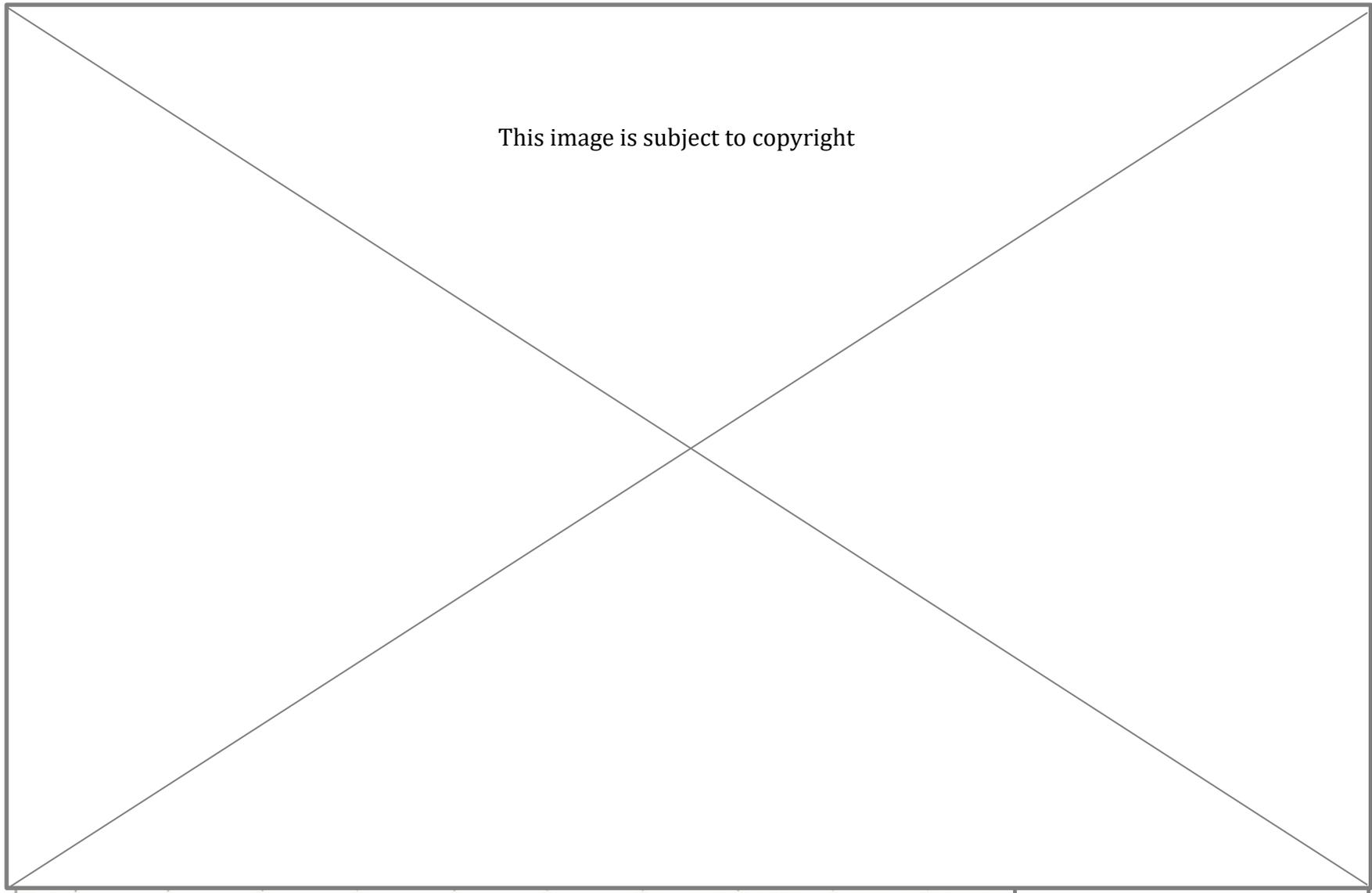


Figure 1: Map of the Kestel mine depicting dating evidence from Willies 1992, 242-3; Willies 1995, p.5; Willies 1993, p.263; Yener and Vandiver 1993, p.261; (original map Willies 1995, p.4)

Arguments against Kestel as an Early Bronze Age mining complex include doubts about the potential for tin production based on the low-grade ore extracted, the reliability of the EBA dating and also whether there is sufficient tin usage in immediately surrounding regions to warrant such an industry (Muhly *et al.* 1991; Hall and Steadman 1991; Muhly 1993). Göltepe is an Early Bronze Age site located 2km from the mine. This occupation/processing site, and the evidence discovered in it, has often been cited as direct evidence in favour of tin mining activities at Kestel (Yener and Vandiver 1993; Laughlin and Todd 2000; Willies 1992) or even sometimes as synonymous with it (Earl and Özbal 1996). Although there are possible and tempting links between the two, the sites ought to be regarded separately and as such Göltepe is discussed in section 3.3, this chapter.

The ceramic evidence at Kestel has been used to date the large underground mining activity “firmly in the Early Bronze Age” (Yener 1994, p.31). Unfortunately, descriptions of the amount of evidence found are subjective, and it is also difficult to pinpoint this data to exact locations within the mine. Figure 1 depicts as accurate a picture as possible of pottery scatters and dating evidence from the literature (Willies 1992, 242–43, 1995, 5; Yener and Vandiver 1993, 261): There are scatters of pottery sherds located in various chambers in the mine; in one chamber there was evidence of extensive use of firesetting to mine the ore (this they have only tentatively dated to the Early Bronze Age because there was also Byzantine evidence present); an in-filled rock joint contained EBI pottery sherds; and EB pottery was scattered in a crawl passage leading off the Large Chamber, however a radiocarbon date of 220 ± 45 years BP (uncalibrated) was also assigned to a piece of charcoal from this passage (Willies 1995, p.5). Fire-setting techniques

and groundstone tools are treated by the paper authors as evidence of EBA mining (Willies 1992, p.244), though it is by no means an exclusively Early Bronze Age technique.

Both large-scale and small-scale mining operations occurred in this mine from the 3rd millennium BCE onwards. However the dating evidence for large-scale mining is ambiguous, and thus far insufficiently linked with the EBA to assume intense exploitation at that time. Regardless of the scale of exploitation, the question of what range of minerals were mined is still unanswered. There is much conflicting evidence and opinion as to the amount of tin ore available in this deposit, both in the past and present, and as to the grade of the ores themselves. There were two mineralising episodes; that of earlier, higher tin bearing ore (presumed to have been mined out), and later haematite (Yener 2000, p.73). Willies has speculated that the ore in the mined areas must have been particularly rich as it was mined to exhaustion (Willies 1992, p.242), and it is estimated that 4000 to 5000 tons of ore were extracted (Yener 2000, p.244).

Today, concentrations of remaining ore contain 0.1 – 1% tin (*ibid.* p.73). However, these values also vary, as an ore sample from the gallery in the first excavation contains 0.07% Sn (Yener et al. 1989, 202), and samples taken from the second season of excavation only contain up to 0.25% Sn (Yener and Vandiver 1993, 263). Hall and Steadman note that other elements (e.g. silicon, iron and aluminium) are present in concentrations larger than 0.25%, but these are referred to as trace elements, and as such they should view the <0.25% Sn as a trace element also (Hall and Steadman 1991, p.218). However a re-analysis of the Kestel ore samples by the opposing team contained no detectable tin at all (Muhly *et al.* 1991, p.213). Doubts

have been expressed as to the availability of this ore to ancient miners. Though the cassiterite-encasing haematite is visually distinctive, the cassiterite within occurs mostly as individual grains ranging in diameter from 10 – 200 µm (0.01 – 0.2 mm). Laughlin and Todd (2000, p.271) maintain that in order to separate the grains from the gangue, a “sharpened tungsten needle and fine forceps” are sufficient.

The presence of alluvial cassiterite deposits in the Kuruçay stream 200 m below the mine is also a debated topic. Muhly states that there are no alluvial deposits surviving in this region (1993), but Yener and Vandiver explain that we should not expect to see the same concentrations of material as found in the 3rd Millennium BCE (1993, p.257). Separating cassiterite from the heavier magnetite is easily done by swirling in water, according to Yener and Vandiver (1993, p.257), but impossible according to Laughlin and Todd (2000, p.272) owing to the almost identical densities of haematite, magnetite and cassiterite. They preferred to deliberately produce magnetite through stages of roasting, which is magnetized and eventually clumps together, leaving the cassiterite grains free. However there is no mention of any magnetite waste found in the vicinity of Kestel, which one might presume to be plentiful if 4000 tons of ore was treated in this way. This process is also contrary to the ore beneficiation described by Earl and Özbal of repeated stages of washing, crushing and panning (1996, p.290).

The assumption is that tin was considered as valuable as gold, therefore even the low grade tin found at Kestel would be worth exploiting (Yener 2000, p.73), despite concerns that ancient miners might not have realised its presence in the first place (Muhly 1993, p.251; Hall and Steadman 1991, p.219). Gold is actually present in this mine and has been known in antiquity to be mined for as little as

4ppm and though that concentration is low, gold's gravity and ability to agglomerate with itself makes it easier to collect through panning than tin (Hall and Steadman 1991, p.228).

3.3 The Göltepe processing site

It is slightly troubling that the site of Göltepe is often used as direct evidence that the Kestel mine was an industrial Early Bronze Age tin mine. The evidence linking Kestel and Göltepe is circumstantial and mainly based on scatters of EBA pottery sherds linking the sites in time, and powdered ore, which is presumed to have been collected from Kestel (Laughlin and Todd 2000, pp.270–1). The ore found in the crucibles at Göltepe is said to “resemble” the Kestel ore (Yener 2000, p.74), but it has an average of three times the tin content (Earl and Özbal 1996, p.295). This higher tin content is described as owing to beneficiation, which may indeed be true; but the powder therefore clearly has a different composition from the Kestel ore and so cannot be used as evidence of a connection between the sites.

Göltepe is an interesting site in its own right. Cultural deposition at the site was spread across 65 ha, and the sherds analysed showed no association with domestic activities, but were remnants of pyro-metallurgical processing (Yener and Vandiver 1993, 216; Laughlin and Todd 2000, 270). Powders found in small crucibles were alongside 5000 crushing tools (Yener 2000). Several experimental archaeology projects were conducted in the following years based on the evidence from Göltepe in the hopes that some light would be shed on its role in a tin mining operation.

Earl and Özbal (1996) selected ten powder samples which could be attracted magnetically, and these samples were analysed; an average value of 2571 ppm tin was found (range: 4514 – 1027 ppm). They also examined twenty-eight powders which were subjected to vanning in a shovel with water, and it was tested how much enrichment of the tin had occurred; four of the twenty-eight samples had been enriched and provided cassiterite which could be separated. Next Göltepe powders, containing cassiterite, iron, and gangue material, which were presumed to have already been enriched and prepared for smelting by ancient craftspeople, were chosen and successfully smelted into prills with an Sn/Fe ratio of 62.25/37.75. Following this trial, one of the four enriched powder samples (5g) was vanned in three stages and smelted in a replica Göltepe crucible made of local clay. This experiment produced 0.175g of metal, which contained 92.17% Sn and 5.17% Fe, proving that it is possible to produce tin from the powdered ores found at Göltepe once enriched.

Nearly a tonne of crucible fragments was found on the Göltepe site, making them a useful resource for experimental work. These fragments were analysed to ascertain processes they may have gone through and suggest what pyrometallurgical use to which they could have been put. The surfaces of the crucibles were analysed for tin by (Earl and Özbal 1996): 4 samples contained >1% tin (1.09%; 2.09%; 2.21%; 3.65%), and the 24 remaining crucible fragments contained an average of 1070 ppm (0.107%). Most crucibles had been exposed to temperatures around 1000°C, which made reduction of cassiterite a possibility.

Yener and Vandiver (1993) analysed twenty-four of the two hundred and fifty crucible fragments found, and found concentrations of tin, aluminium, silicon, iron

and titanium in the surfaces, though they consider tin to be the major element. Tin was not found in the surrounding soil, nor was it found in the outer surface of the crucibles and it was therefore concluded that the tin related to the function of the crucible. Like Earl and Özbal, they estimated 1000°C as the upper firing limit, but thought most crucibles had experienced temperatures between 700 - 800° C. Arsenic was also found, in varying amounts, on the surfaces of some of the crucibles. It was believed that arsenic must have been intentionally added as it does not occur in the Kestel deposit, though this could be an indication that ores other than those from Kestel were being processed. Göltepe therefore seems to have been capable of producing tin on a large-scale, though whether it was in connection with Kestel mining activities is still uncertain and it is equally possible that Göltepe was supplied with ore from elsewhere.

3.4 Regional patterns of tin use to support Kestel tin

If Göltepe and Kestel were linked and producing as much tin as hypothesised, there are still some doubts as to whether patterns of bronze usage in EBA Anatolia can support the theory. If the Kestel tin mine, through Göltepe, was supplying the whole of Southwest Asia with tin, the local use of tin needs to be studied (Muhly 1993, p.240). The tin-bronzes found at Tarsus, a site close to Kestel but across the mountains, have a tin content lower than 5%, with 5.29% being the absolute highest (*ibid.* p.241). Whereas the tin-bronze assemblages from the west and central regions of Anatolia appear to show what could be considered as a more classical pattern; bronze artefacts containing around 10% tin (*ibid.* p.241).

Though the binary notion of “true bronze” (Muhly 1993, p.241) and ‘other’ has now fallen out of favour, the difference in tin content to the north and south of the Taurus Mountains is still important with regards to tracing the path of the tin trade. The source of tin is searched for often with specific regard to the tin-bronzes of Mesopotamia and the Ancient Near East containing 7% to 10% tin (Laughlin and Todd 2000, p.269). The tin content of objects along a trade route might be expected to be higher, or at least of equal concentration, near the source as at the trading destination, however the region closest to the Kestel mine on the proposed trade route via the “north south Ececiş fault line” (Yener and Vandiver 1993, p.209) has a significantly lower tin content, and it seems unlikely that the tin content of bronzes would increase the further from a major source the traders travelled.

The remaining possibility if Kestel tin was traded in bulk is that it occurred in a northerly direction, which would preclude trade to Mesopotamia unless it occurred via the Caucasus. The low tin present in the Mediterranean and Eastern Anatolian copper assemblages is most likely indicative of the end of the tin trade route that came from the south and west, travelling overland through Syria along the Euphrates and consequently via Ugarit (Muhly 1993, p.253; De Jesus 1978, p.101).

3.5 Summary of the Kestel mine as a source of tin

A level of Early Bronze Age presence at Kestel is definitely attested by pottery, but it cannot be irrefutably linked to the large-scale mining activity which created the

underground tunnels. Firmer evidence is needed to date the large-scale workings to this time. Clearly it cannot be ruled out as a possibility, but much more solid evidence is required for Kestel to be viewed as anything more than small scale, local EBA exploitation. Then there is the ore itself. It does appear possible to produce tin from it, but the process is laborious and seems improbably complex for a large-scale industry, especially given the presence of more readily accessible and valuable minerals.

The linking of Göltepe and Kestel seems to be founded on little more than proximity and a possible overlap in occupation period; it should certainly not be used to bolster the theory of large-scale tin mining at Kestel. On the other hand, it has been proven that tin can be smelted in both the crucibles and the powdered ore found at the site. The exclusivity of tin smelting at this site is not proven, nor is the extent of the industry found there. Enthusiasm and tenuous evidence appear to be the main bulk of proof in the case of the Kestel mining complex. Though it is by no means impossible that Kestel was extensively mined for tin in the Early Bronze Age, much firmer evidence is needed before it can be viewed as a large-scale industry, complete with miner's village, supplying such a vast area as Southwest Asia.

4 Trade and communication in Southwest Asia

4.1 4th millennium BCE

In the mid-4th millennium BCE an apparently sudden and widespread distribution of Uruk-style architecture, motifs, ceramic styles and administrative procedures spread out from Southern Mesopotamia, reaching as far north as the Taurus Mountains (Sagona and Zimansky 2009, p.176), as far east as the Iranian Plateau and as far west as the Nile Delta (T. F. Potts 1993, p.383). There are various different forms of Uruk presence in settlements throughout this region; colonies which contain exclusively southern Mesopotamian assemblages as at Habuba Kabira and Jebel Aruda; *enclaves* or trading stations which are distinct sectors within pre-existing indigenous centres like Hacinebi and Hassek Höyük in southeast Turkey, and Godin in Iran; and small Late Chalcolithic settlements influenced by the nearby Uruk *enclaves* or containing Uruk-related material (Stein 1999, p.96).

It is also debated to what extent the Uruk Phenomenon intruded into the Caucasus. Pitskhelauri (2012) outlines two waves of 'Uruk' migrations into the region; the first of which occurred in the 5th and 4th millennium BCE and is described as the regional stimulus for the development of Maikop and Kura-Araxes Cultures. Kavtaradze (2013) is of the opposite opinion – that the pre-Uruk Culture (or Ubaid) was actually shaped by the cultures in the Caucasus. There were certainly Uruk-related objects found at sites within the Caucasus, but the sites themselves are not regarded as Uruk outposts as in the Upper Euphrates, as the levels of

influence required to control trade would be unmanageable from that distance (Kavtaradze 2013, p.8). The lack of a chronological consensus between the Caucasus and Mesopotamia and the ambiguity of firm dating evidence at this time in the Southern Caucasus (Helwing 2017; Kohl 2009) renders the topic of Uruk “expansion” into the Caucasus uncertain, therefore the Uruk Phenomenon will be only considered up to the highland regions of Anatolia and Iran and no further.

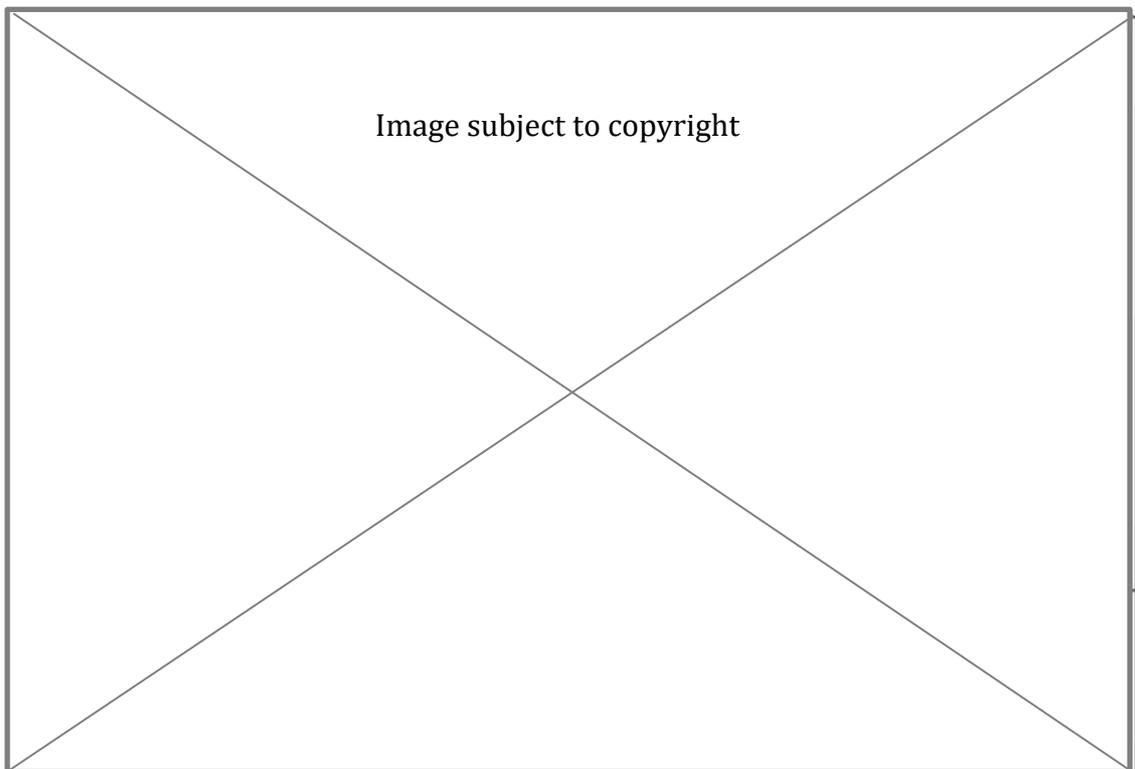


Figure 2: map depicting the regions of Uruk homeland and expansion (Greenberg and Palumbi 2015, p.112)

A series of Uruk colonies and *enclaves* were settled along both the Tigris and Euphrates rivers and their tributaries - direct trade routes from Syro-Anatolia and the highlands of Iran to Southern Mesopotamia. Some colonies were strategically located at convenient areas where overland and river trade routes cross (Aubert 2013, p.175) highlighting the importance of trade behind the intent to settle. The

desire for access to raw materials of stone, metal and timber are undoubtedly what originally drove the initial contact and exchange network as Mesopotamia itself lacks most of these resources (Crawford 1991; Sagona and Zimansky 2009; T. F. Potts 1993). Rather than the previously assumed colonial enterprise into cultural backwaters to acquire these resources, it has emerged that complex social structures and craft specialisation were already in place in the region before contact with Uruk Mesopotamia. For example, Hacinebi was already producing artefacts and materials which would later be traded south (Rothman 2012, p.5). It seems that the Uruk Phenomenon took advantage of production systems which were already in place rather than initiating them.

Uruk-related sites reach into resource rich areas such as the copper mines in Ergani Maden (Aubert 2013, p.171) but the Uruk presence in these regions is not as strong as along the trade routes (Stein 1999, p.101). It can therefore be inferred that Uruk Mesopotamia was not involved in extraction or distribution of raw material, only in its acquisition. The quantity of copper-base metal in Anatolian burials and settlements by the mid-4th millennium BCE indicates that copper was heavily in demand amongst the indigenous population as well as foreign populations. It is therefore possible to assume that the indigenous population itself was in charge of mining and extraction and controlled both the quantity and quality of the ore that was bound for trade, thus retaining their agency and playing a crucial role in the trade model. Another indication of their consent to trade is the peaceful cohabitation of traders and original settlement inhabitants: the Uruk *enclaves* were therefore intrusive sites but tolerated or even welcomed by the indigenous population (Aubert 2013, p.172).

The remains of ore and metallurgical activity which occurred in colonies and *enclaves* situated along the rivers heading towards Southern Mesopotamia demonstrates that bulk trade of metal was occurring in ore form (Aubert 2013, p.170; Algaze 2009, p.94). Finished artefacts were traded back north by foot and donkey pack, as attested by cylinder seals and seal impressions from Uruk-related sites in northern Iraq, northern Syria and Southeastern Anatolia (Algaze 2009, p.133; Rothman 2012, p.3). This trading network appears more reciprocal than exploitative. If using Renfrew's model (1975, p.520) of exchange, it would appear that trade south was *emissary trading* or *colonial enclave trading*, and trade north was *down-the-line* trading which occurred from village to village given that the route north by foot would take much more time than the river-borne trade south. With *down-the-line* trade you might expect to see more reprocessing and recycling occurring as the supply is not necessarily steady or consistent and might be conducted by freelancing individuals, allowing more freedom over what is exchanged.

Roughly contemporaneous with the beginning of the Uruk Phenomenon was the Maikop Culture in the Northern Caucasus, famous for its richly furnished, metal-heavy Kurgan burials (Kohl 2009, p.91). The Maikop Culture is believed by some to be the northern fringe of a larger Northern Mesopotamian cultural zone (Trifonov 1994, p.358). Its position on the fringes of Mesopotamian culture is under question owing to the mystery of its origins: were they to be found in the Southern Caucasian Leilatepe Culture which shifted north, or did Ubaid/Pre-Uruk migrants have a cultural influence on Maikop development (Museyibli 2016; Pitskhelauri 2012)? There do appear to be parallels between the Northern Caucasus and Near

Eastern traditions (Trifonov 1994, p.358). One example of such similarity is that between the jewellery types found in Maikop Burials and at the Royal Grave at Ur (Ivanova 2007, p.18). The lack of Mesopotamian ceramics in Maikop levels could be seen as an absence of communication, however the presence of lapis lazuli could indicate trade through Mesopotamia (Ivanova 2007; Abramishvili 2017). Rezepkin (2017) reports southern influence in the North-western Caucasus during the Late Chalcolithic, and sees this influence as directly related to the Uruk Culture. It is interesting to note that Maikop is thought to be linked to either Leilatepe or Uruk origins, when Leilatepe itself is also thought to have originated with or to have been linked with Ubaid or Uruk cultures, depending on the current chronological thought (Akhundov 2014).

Chernykh (2017b) on the other hand, sees the Maikop Culture as nomadic (possibly horse-riding) raiders, who frequently looted from regions to the south, which would also explain similarities with Leilatepe material. At the very least he considers the Caucasus to be a bridge between Southwest Asia and Central Asia until the end of the 3rd millennium. This view is more in keeping with Kohl (2009). In the past the Maikop Culture has been seen as the metals intermediary between the north and south, at the centre of the metals trade.

From the mid-4th millennium BCE a new ceramic horizon (Kura-Araxes) spread across the highland areas of the Southern Caucasus along with permanent, rather than seasonal, occupation and distinctive architectural features (Batiuk 2013, p.450; Palumbi 2016, p.14). During the latter half of the 4th millennium this Early Transcaucasian Culture (ETC) spread across much of Southwest Asia (Figure 3) but has collected different names in each geographical area owing to the

regionalisation of both style and archaeology as a discipline; the Kura-Araxes in the southern Caucasus, Yanik in northwest Iran, Karaz in eastern Anatolia, Red Black Burnished Ware in northwest Syria, and Khirbet Kerak in Israel and Palestine (Batiuk 2013, p.450). Metallurgical activities occurred on a large-scale but at a household level of production (Palumbi 2016, p.25). Metalworking seems to have been so commonplace that copper was relied upon more to produce utilitarian objects than ornamentation; little or no value was placed on it as a wealth item (*ibid.* p.26).

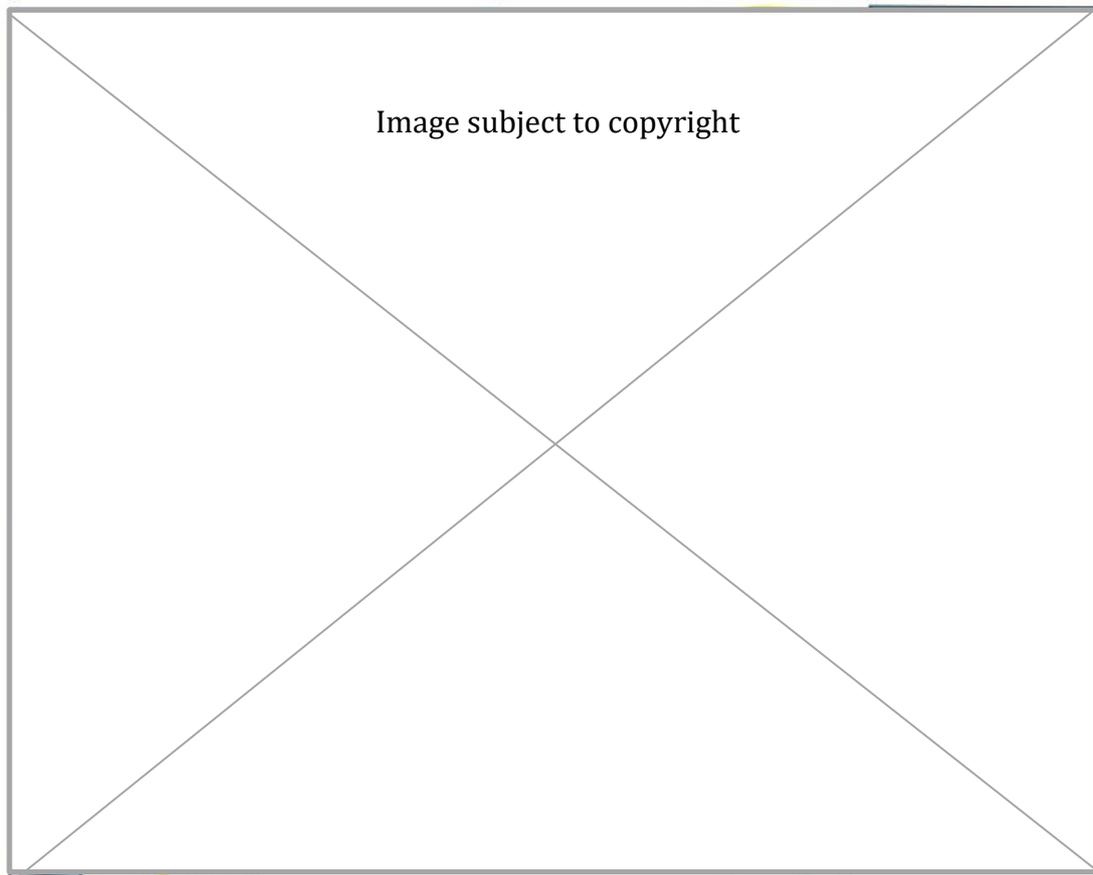


Figure 3: map depicting the spread of Kura-Araxes culture over time (Rothman 2015, p.9191)

The Iranian Plateau was connected with the Early Transcaucasian Culture and the Uruk Phenomenon, while administrative writings and devices show that it was

also closely connected to Turkmenistan, Bactria, the Indus and the Arabian Gulf towards the end of the 4th millennium BCE, and even more so at the beginning of the next (T. F. Potts 1993, p.382)(Potts 1993, 382). The Northern Levant, on the other hand, remained insular and decentralised until the 3rd millennium BCE (Greenberg 2013, p.5). It was a similar picture in Cyprus during the Middle Chalcolithic (3400 – 2900 BCE) where the material culture remained homogenous across the island and there was a lack of foreign imports, though there did appear to have been growing social inequality (Peltenberg 2013, p.4). Compared with the relatively slow transition into the Bronze Age on Cyprus and in the Northern Levant, the Southern Levant was well into the Early Bronze Age by the mid-4th millennium BCE. Whereas Anatolia was linked to Uruk Mesopotamia, the Southern Levant was in contact with Egypt. Despite this contact, craft specialisation and active interaction in long distance trade networks remained limited in the Southern Levant and only began to really develop in the early 3rd millennium BCE (Greenberg 2013, p.3).

4.2 *3rd millennium BCE*

At the turn of the millennium the Southern Levant's trading networks and the Early Transcaucasian Culture were flourishing, whereas the Uruk Phenomenon and Maikop Culture collapsed. Many of the colonies and *enclaves* along the Euphrates valley were abandoned or destroyed and Uruk-style artefacts disappear (Stein 1999, p.92). Despite this collapse, both in long-distance trade routes and urbanism, evidence from the 3rd millennium suggests that metals continued to be

traded (Rothman 2012, p.9; Crawford 1991, p.147; Özdoğan 2007, p.23). Mesopotamian trading focus shifted away from Syro-Anatolia and towards the east, with copper especially coming from the highland regions of Iran rather than the Taurus Mountains (T. F. Potts 1993, p.384; Mark 1997, p.10). Through Iran, Mesopotamia was now in contact with Turkmenistan, Bactria, the Indus and the Arabian Gulf.

During these first few centuries of the 3rd millennium BCE the settlements in Syro-Anatolia and the Upper Euphrates had regressed to small, decentralized, agriculture-based villages (Liverani 2014, p.89; Matney 2012, p.556). This can be seen in contrast to the urbanisation of the Central Plateau which sees an accumulation of wealth deposited in rich burials (Rothman 2012, p.9; Crawford 1991, p.147; Özdoğan 2007, p.23). It is not clear where the raw materials were coming from; their presence could indicate a continuation of the mining operations from the previous period in the Taurus Mountains, prestige gift exchange among elites rather than commercial trade or perhaps, as indicated by ceramic and stylistic similarities, contacts with the Balkans, southeast Europe and/or the Southern Caucasus (Stech and Pigott 1986, p.54; Steadman *et al.* 2008, p.49).

The Early Transcaucasian Culture did not collapse at the same time as the Uruk Phenomenon; in fact the arrival of Khirbet Kerak Ware in the Southern Levant by 2800 BCE indicates that the culture continued to spread for several centuries (Palumbi 2016, p.28). Extensive trade can be tracked by ceramic traditions and techniques, architectural similarities, and obsidian from Lake Van. Palumbi (2016) has suggested a link between the collapse of the Uruk Phenomenon and the

successful expansion of the Early Transcaucasian Culture, as many ETC-related traditions become apparent in the Uruk-abandoned regions.

Owing to certain similarities between the Maikop burials and the Royal Tomb at Arslantepe, Chernykh (2017b, p.155) thinks it more likely that it was the Maikop tribes who deliberately destroyed the site c. 3000 BCE and resettled it, rather than the advancing Kura-Araxes (ETC) Culture, as believed by the site's excavators. The similarities with Maikop are based on the Royal Tomb resembling a Kurgan burial, and the presence of arsenic-nickel-copper alloy in both regions. On the other hand there are frequently cited links with Syro-Mesopotamian culture rather than Northern Caucasus during the site's development, which were halted at the turn of the 2nd millennium BCE after a devastating fire, and the links and the material culture which was mixed in with local ware were with the Southern Caucasus (Frangipane 2012; Palumbi 2016; Marro 2012).

Khirbet Kerak Ware (ETC) arrived in the Southern Levant just as urbanisation and long-distance contacts began to decline in the region (Greenberg 2013, p.7). This coincided with a period of developed urbanisation in the Northern Levant and its increased interaction in long-distance trade networks, especially with Egypt (*ibid.* p.7). It is also during the early 3rd millennium that Cyprus began to take part in inter-regional trade. Cyprus' main trading contact in this period was Southwest Anatolia, as attested by the similarity in stamp seals (Peltenberg 2013, p.11). Continued links between Southeast Anatolia and Syro-Mesopotamia are evident in settlement models, showing a clear distinction from those north of the Taurus which were built and remained in a distinctly Anatolian style (Özdoğan 2007, p.23). This region also shows evidence of continued trade along the Euphrates

River: Mari, a large urban settlement which was established in early 3rd millennium BCE (Bachhuber 2011, p.165) and located centrally for trade, shows signs of smelting and craft specialisation between 2900 and 2550 BCE (EBI). Ores, refined metals, and finished products were therefore still undoubtedly being traded, but there is a no evidence of centralised organisation (Margueron 2014, p.136). Mari was completely abandoned at the end of the Early Dynastic II/EBI (c. 2700BCE) and was not re-occupied until later in the 3rd millennium – though its central location along the Euphrates enabled the site to quickly recover its importance as a trading post between Mesopotamia and the northern and western regions (*ibid.* p.136).

From Early Bronze Age II (c. 2700 BCE) a widespread development of social complexity and urbanisation took place across much of Southwest Asia and a fully flourishing trade network emerged with it (Liverani 2014, p.93; Frahm and Feinberg 2013, p.1868; Matney 2012, p.563). It is at this time that the Mesopotamian supply of copper switched from the Iranian highlands to Magan (Eastern Arabia), via Dilmun and trade along the Persian Gulf, though the initial imports were only in small quantities (T. F. Potts 1993, p.391; Potts 2003). Long-distance contacts eventually pushed north of the Taurus Mountains into the Central Anatolian plateau and during this period in Anatolia we begin to see some of the richest consumption of wealth in the region, specifically in the form of tin-bronze in burials (Steadman 2012, p.2; Stech and Pigott 1986, p.57; Bachhuber 2011, p.164). The second quarter of the 3rd Millennium BCE appears to have included more regions of Southwest Asia within its communication network than ever before.

By the mid-3rd millennium BCE the Early Transcaucasian Culture was in crisis, and related settlements were abandoned by 2400 BC (Palumbi 2016, p.29). There was no corresponding decrease of social complexity in the Southern Caucasus, where Kura-Araxes culture continued unchanged for a time, though contemporary with it were the emerging Kurgan cultures. These cultures represent a socio-economic shift, visible in the unequal displays of extraordinary wealth within funerary traditions of the Martkopi-Bedeni Cultures (Smith 2005). Increased social differentiation is visible in the richly furnished elite burials which foreshadow, but are not identical to, the burials of the Middle Bronze Trialeti period beginning in 2200 BCE (Tedesco 2006, p.94). The Southern Caucasus assemblage displays parallels with that of the Northern Caucasus at this time and is almost certainly supplying the Northern Caucasus with arsenical-bronze (Chernykh 2017a; Chernykh 2017b). However, the post-Maikop cultures began to have a stronger connection with northern cultures during the 3rd millennium, and eventually contacts and influence moved into the steppes and spread west beyond the Black Sea, for example the Yamna Culture (Kristiansen 2007; Chernykh 2017a). Syro-Anatolia, the Northern Levant and the Upper Euphrates became a focus of interest for Mesopotamia once more (Greenberg 2013, p.9).

Despite the disappearance of the Early Transcaucasian Culture from long distance trading networks, by the mid-3rd millennium BCE trade and inter-regional contact were flourishing throughout Southwest Asia. Trade and craft specialisation intensified, and mass production increased (Riehl and Deckers 2012, p.19). Material culture and technological developments were shared from northern Syria to south and central Anatolia (Şahoğlu 2005, p.340). The central plateau saw

greater accumulation of wealth, increased trade, further development of metallurgy, and the import of precious materials (Özdoğan 2007, p.13; Ur 2011, p.404; Erarslan 2009, p.268). Connections between the Anatolian Plateau and Northern Mesopotamia strengthened: middle Euphrates ceramic assemblages and ‘Syrian bottles’ became ubiquitous across the Middle Euphrates, Syro-Anatolia and across the Central Plateau into western Anatolia (Steadman 2012, p.4; 1986, p.31; Zimmerman 2007, p.66; Massa and Palmisano 2018, p.75)(Figure 4). Similarly, vessels of Western Anatolian origin appear to have spread in a southeast direction and into the Middle Euphrates (Steadman 2012, p.4; Ökse 2007, p.40) (Steadman 2012, 4; Ökse 2007, 40).

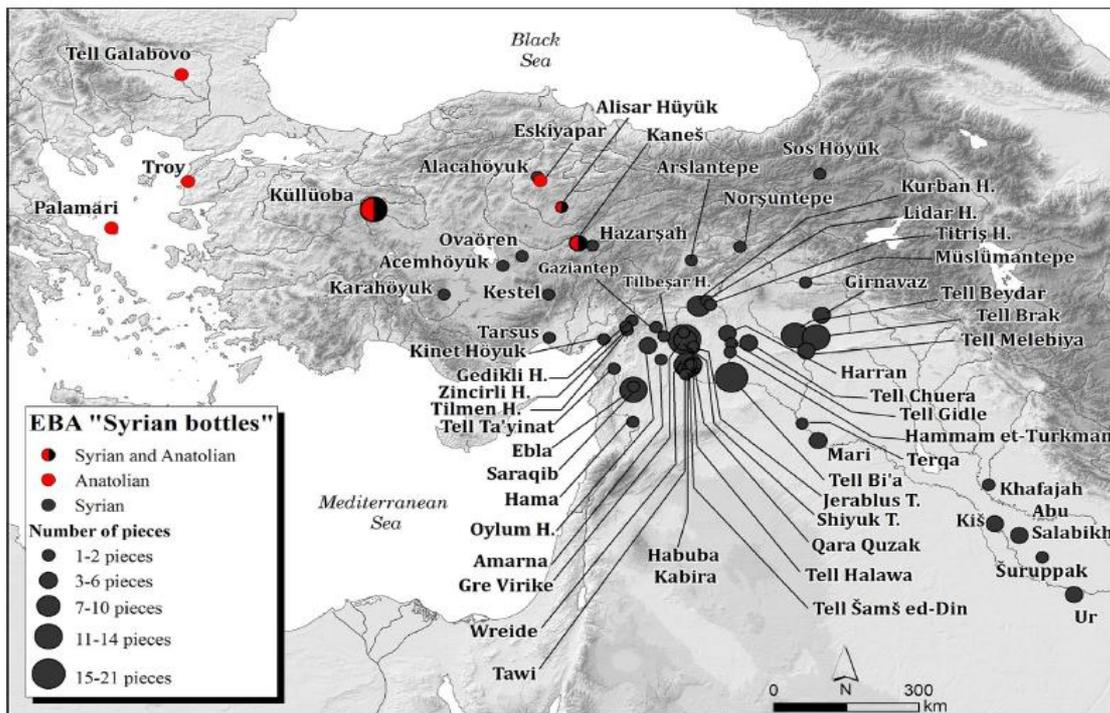


Figure 4: map showing the location of “Syrian” bottles (black dots) and local imitations (red dots) across Anatolia, the Levant and Mesopotamia (Massa and Palmisano 2018, p.76).). This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/3.0/>)

Both ideas (e.g. the potter's wheel) and finished goods were being exchanged across Southwest Asia and, contrary to the Uruk period, indigenous Anatolian innovations and goods were also sought in the south. Connections between this extended Upper Euphrates region and Southern Mesopotamia appear to have existed solely for the purpose of trading metal, specifically tin-bronze and silver (Stech and Pigott 1986, p.57). From the mid-3rd millennium BCE Iranian imports are no longer as visible in Mesopotamia, though trade is documented at some settlements along the overland route (T. F. Potts 1993, p.391).

Routes which connected the Central Plateau with Eastern Anatolia and the Upper Euphrates basin through the Anatolian highlands show evidence of having being in use during the latter part of the 3rd millennium BCE (Ökse 2007). In the Akkadian period (2300 – 2200 BCE) a renewed settlement pattern emerged along the Euphrates River, as did signs of increasing social complexity in the form of hierarchical settlements (Frahm and Feinberg 2013, p.1867; Stech and Pigott 1986, p.33). Titriş Höyük was the capital of a small city-state system which appeared in the Euphrates River basin (Matney and Algaze 1995, p.33). It was situated on the overland route between Northern Mesopotamia and the Taurus mountains, giving it a vital role in long-distance trade and exchange (Erarslan 2009, pp.268–9). Distribution of obsidian and a shared material culture between Northern Mesopotamia and Eastern Anatolia has been suggested as operating through nomadic or semi-nomadic exchange networks (Frahm and Feinberg 2013, pp.1874–5).

After the collapse of the Akkadian Period in 2200 BCE there was a shift in settlement pattern across Northern Mesopotamia and many sites were completely

abandoned (Matney 2012, p.564). There was actually an increase in the number of sites at this time but a significant decrease in settlement-size and population (Erarslan 2009, p.271). Peltenberg notes that monumental or public structures are completely absent in the post-Akkadian period (Peltenberg 2000, p.2). This period of de-urbanisation lasted around 300 years, but it is unclear how much long-distance exchange was really halted. Administrative seals and material culture discovered along the Upper Tigris River suggest that Northern Syria, Northern Iraq, Central Turkey and the Upper Tigris Valley were still in close contact (Erarslan 2009, p.279).

Although Cyprus was connected with Southwest Anatolia from 2400 BCE, bringing innovation and imports to the island, this came to an end after little over a century. Cyprus then went through a period of isolation once more, with no imports from any of the surrounding regions for the final centuries of the 3rd millennium. It was only at the beginning of the 2nd millennium BCE that Cyprus regained its international trading contacts, and with this we see the reappearance of tin-bronze on the island (Webb 2013). Though the Northern Levant was in contact with Mesopotamia and the region was involved in large-scale trade of luxury goods, the settlements and culture remained more agriculturally focussed. At the end of the 3rd millennium BCE settlements in the southern Levant were gradually abandoned and the region continued its decline. There is no evidence of a similar collapse in the Northern Levant, which continued to flourish into the next millennium (Greenberg 2013, p.10).

4.3 2nd millennium BCE

The Circumpontic Metallurgical Province began to dissolve in the late 3rd millennium BCE and began a period of spatial and territorial “stagnation”, though technological innovations continued (Černyh *et al.* 1991; Chernykh 2017b, p.190). The face of the metallurgical traditions and similarity in form and character split from a central tradition to five separate fragmented *Metallurgical Provinces*: European, Caucasian, Iranian-Anatolian, Eastern Mediterranean (Aegean), and West-Asian (*‘Eurasian Metallurgical Province’*). These regional traditions all clearly displayed a shared heritage, but were separated and not necessarily connected by trade (Chernykh 2017b, p.211).

Settlers returned to Northern Mesopotamia after several centuries of decentralisation, but the nature of settlement was altered; a new, highly integrated political landscape is visible in the archaeological record, one which took the form of kingdoms and tribes rather than large urban centres or small agricultural villages (Ristivet 2012, p.39). There is evidence of a growth in population but most settlements, though larger than those from the immediately previous period, remained self-sufficient villages (Erarslan 2009, p.272). The region was characterised by pastoral nomadism and even the major capitals in the region were not as densely populated as before (Ur 2011, p.25). Despite this altered form of socio-political complexity the sites in the region took part in long-distance exchange and there is evidence of advanced craft specialisation, especially in the production and refinement of metals (Erarslan 2009, p.279). In contrast, the

Anatolian Plateau was more politically fragmented at the beginning of the 2nd millennium BCE than before, but excavated evidence demonstrates the presence of thriving centres along a hierarchical structure: small city-states, real territorial states, and villages (Michel 2011, p.6). The long-distance exchange network reveals contacts between Anatolia, Mesopotamia, Iran, and the Southern Caucasus (Laneri and Schwartz 2011; Abramishvili 2017).

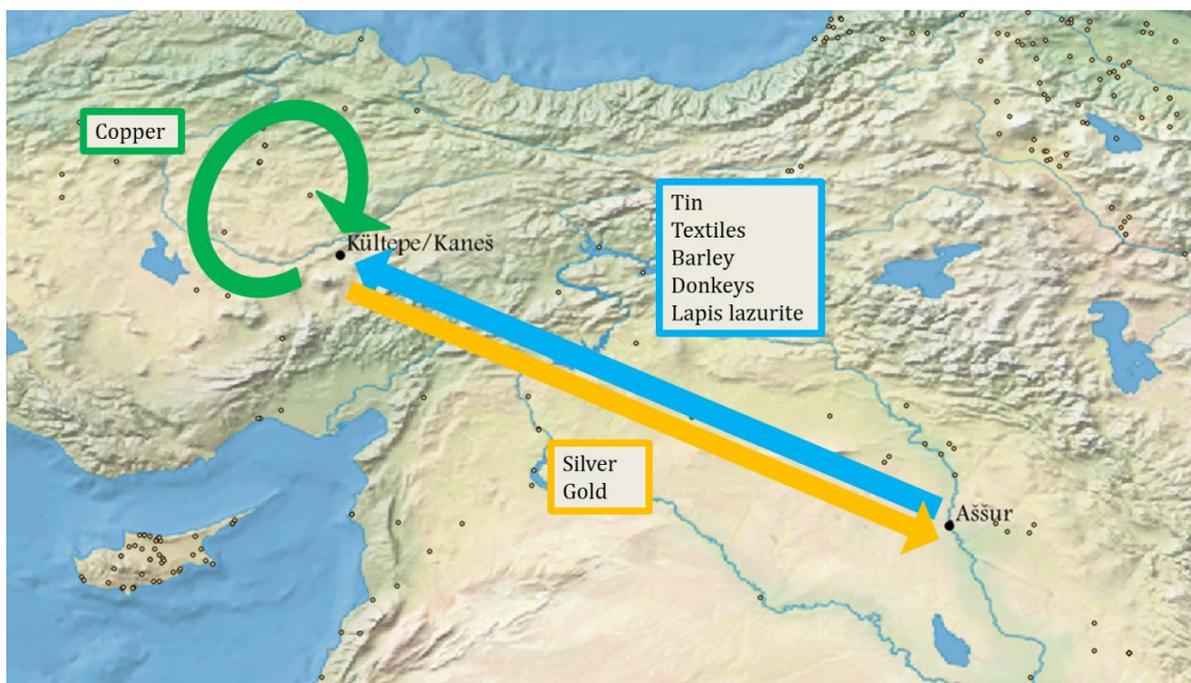


Figure 5: map of Old Assyrian Trading network and rough direction of products exchanged in the early 2nd millennium BCE based on discussion in this section

The dominant trading network in the early 2nd millennium BCE was that of the Old Assyrian period (Figure 5), during which time Central Anatolia (and some sites in Southeast Anatolia) were connected with Aššur, a purely commercial centre situated on the Tigris River (Aubet 2013, p.271). The city of Aššur controlled the traffic into Anatolia but Anatolian rulers had jurisdiction over the merchants (Collins 2007, p.26; Gawlikowska 2009, p.44); all the details of this commercial relationship were drawn up in detailed contracts and treaties (Aubet 2013, p.267).

Assyrian traders set up colonies or *kārums* over a 60 mile radius within Anatolia and many of these colonies were established in pre-existing centres (Bryce 1998, p.14; Aubet 2013, p.332; Collins 2007, p.26). Kaneš was the organisational centre of the northern part of this network and as such the merchandise on its way to Anatolia went first to Kaneš, before being redistributed amongst other Anatolian centres (Aubet 2013). The Old Assyrian Trading Network is visible only through the contracts, treaties and written documents from the archive in Kaneš (Koliński 2009, p.97): the Assyrians in Anatolia shared the same material culture as their indigenous hosts making their presence indistinguishable, and there are no contemporary indications in the archaeological record from Aššur to suggest that a large-scale trading organisation, let alone its traders, existed at the settlement (Collins 2007, p.28; Aubet 2013, p.274).

It is clear from the archived texts that the main imports were tin, textiles, lazurite, donkeys, and barley which were traded for gold and silver to be taken back to Aššur (Muhly 1973, p.292; Koliński 2009, p.100; Collins 2007, p.25; Aubet 2013, p.288). Anatolian copper from local mines was traded by the Assyrian merchants but it was only traded in Anatolian centres and rarely brought back to Aššur (Michel 2011, p.8; Aubet 2013, pp.296–7). The impetus behind this commercial enterprise was the acquisition of silver – occasionally the Assyrian merchants traded tin or cloth for local merchandise, but this was then sold on elsewhere in Anatolia in exchange for gold or silver before the journey back to Aššur (Koliński 2009, p.99). It has been estimated from available texts that at least 80 tonnes of tin was imported into Anatolia, suggesting that local sources were not exploited on a large-scale (Bryce 1998, p.27). The selling price of tin in Anatolian settlements was

twice the selling price of that in Aššur indicating the high value, and perhaps rarity value, placed on it in the region (Muhly 1973, p.292).

The source of tin imported by the Assyrians is never mentioned, though it is thought by some to have come from the mountains in Iran (Bryce 1998, 27; Aubet 2013, 287; Moorey 1985, 129; Muhly 1973, 290). Susarra, located in the Plain of Rania in Iran on the route to Aššur, was stated in a letter to be a place where large quantities of tin could be obtained. When this site was destroyed there was a corresponding interruption of tin imported into Kaneš (Aubet 2013, 292).

The Assyrian merchants avoided regions of political unrest and upheaval, and as such trade ceased for several decades after the destruction of Kaneš in the mid-19th century BCE (Bryce 1998, p.35). When this occurred for a second time during the political instability of the Hittite Old Kingdom, the Assyrians withdrew again from the region and did not return (Collins 2007, p.37). With the end of Assyrian presence in Anatolia came the end of written records and the following period is obscure (Bryce 1998; Collins 2007). When the Hittite Empire was fully established by the mid-2nd millennium BCE very few of the previous major Anatolian centres had any residual significance (Bryce 1998).

From the mid-2nd millennium BCE, social organisation in the Northern Caucasus underwent a dramatic shift. There was greater focus on the local community, resulting in greater regional isolation and inward-looking societies. These societies were organised along a complex, but horizontally hierarchical lines (Reinhold 2017, p.346). The picture in the Southern Caucasus, on the other hand, is the opposite: increased vertical social hierarchy and more monumental architecture

(*ibid.* p.349). The material culture is also so homogenized and unified across the whole of the Southern Caucasus, that it can be classified as one cultural horizon: the Lchashen-Metsamor Culture (Lindsay and Greene 2013, p.694). The most striking thing about the Caucasian Metallurgical Province at this time was the large number of metal weapons deposited in graves – they were skilfully manufactured with time-consuming processes but deposited unused in graves (Chernykh 2017b). Despite this lavish use of metal in burials, the settlements remained relatively unspectacular. Though Southern Caucasus involvement in long-distance trade during the 2nd millennium BCE is implied by some scholars (Laneri and Schwartz 2011, p.1), Chernykh (2017a, p.485) states that the Northern and Southern Caucasus remained isolated from both their northern and southern neighbours.

As mentioned previously, Magan copper was imported to Mesopotamia via the Persian Gulf throughout the 3rd millennium BCE and was then distributed to other regions of Southwest Asia (Knapp 1986). The ever-increasing supply of Magan copper to Southwest Asia continued into the early 2nd millennium BCE, but organization of this trade was altered in the 2nd millennium: trade was conducted exclusively via Dilmun (Edens 1992). Whether it was owing to a price inflation of copper, the reputation of Dilmun merchants dealing in substandard quality copper, the disruption of trade routes by Hittite military expeditions, ethnic movements, or environmental decline is unknown, but c. 1750 BCE trade between Dilmun and Mesopotamia collapsed (Oppenheim 1967, pp.82–3; Knapp 1986, p.44; Edens 1992, p.132). Fortuitously, it was at that time that Cyprus (Alashiya) is recorded in cuneiform texts as initiating trade of copper to Mari and Babylon (Knapp 1986).

The Eastern Mediterranean trade network expanded drastically in the mid-2nd millennium BCE connecting Europe, Asia, and Africa (Grave *et al.* 2014).

From c. 1750 BCE to c. 1200 BCE, both the trading networks and the system of diplomacy that characterise this period, were flourishing and connected Southwest Asia on a broad scale. Independent and neutral, the ports on the Levantine Coast connected broader trade networks: the maritime trade and the land-based trade across Southwest Asia (Knapp 1986). Regions producing specialised goods interacted with the central trading centres such as Mari, Aššur, and Ebla: tin came from the east, possibly accompanying lapis lazuli, and copper came from the west (*ibid.*).

The late 2nd millennium BCE was a period of intense internationalism and increased territoriality. Figure 6 shows the development of regional territories throughout the period. The complex system that was fully developed by 1400 BCE involved a region which spanned Western Iran to the Aegean Sea, and Anatolia to Nubia. The main players in this international game were Kassite Babylonia, Hittite Anatolia, Egypt, Mitanni, Assyria, Elam on the eastern fringe, and Mycenae and Alashiya (Cyprus) on the western fringe. During this time there is evidence of violence and a trend toward fortification in the Caucasus, but there is also evidence of contact with Northern Mesopotamia, Egypt, and many other kingdoms belonging to the 'Age of Internationalism', suggesting Caucasus involvement in the diplomatic period, though not as intensely focussed as neighbouring regions' participation (Bobokhyan *et al.* 2017). For the first time in Southwest Asia there was no one dominant polity or trading partner (Van de Mieroop 2016, p.137). The main exception was the area of Syro-Palestine where the states remained in a

similar template to that of the preceding period: cities controlling a small surrounding state (*ibid.* p.141–42). This region, located between two large and competing territories which had commercial and political interest in it, was perhaps not afforded the time or space needed to expand or develop.

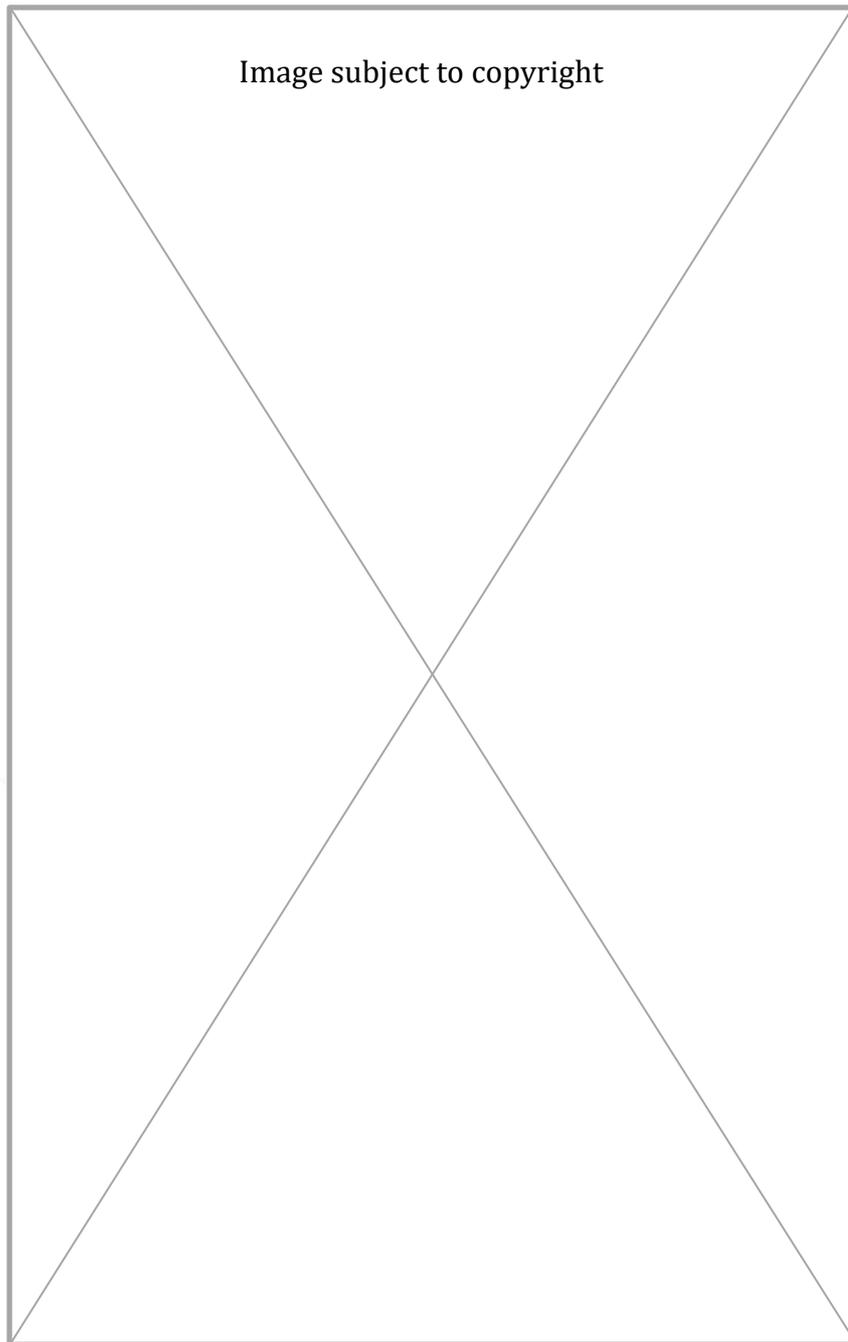


Figure 6: series of maps depicting political entities of the Late Bronze Age, involved in diplomatic correspondence and treaties (Van de Mieroop 2016, p.140)

Raw materials and finished goods, both utilitarian and luxury, were an important part of the communication between these states (Knapp 2008, p.131). This is both in the form of production and manufacture, but most essentially in various forms of exchange underlying a complex diplomatic system. Alongside written communication, there were other forms of contact, such as the Amarna letters, diplomatic treaties, royal marriages and even military action – all of these events were accompanied by gift exchange based on reciprocity (Van de Mieroop 2016, p.146). These forms of exchange existed alongside commercial trade.

Shipwrecks off the southern coast of Turkey, notably the Ulu Burun and Cape Gelidonya shipwrecks, give some indication as to the international nature of trade during the Late Bronze Age. Nine or ten different cultures are represented in the Ulu Burun cargo (Ward 2003, p.529) and similarly many different cultures are represented in that from Cape Gelidonya (Maddin *et al.* 1977). The Ulu Burun shipwreck was unique in that a tonne of tin was found in it: previously the largest amount of tin discovered in archaeological contexts was less than 100 kg (Pigott 2011, p.275). Ten tonnes of copper were also discovered on the Ulu Burun shipwreck as well as many other raw materials and finished products believed to be bound for the Aegean (Carlson 2003, p.136).

The level of diplomacy and ostensibly good relations reflected in letters, treaties, and gifts is misleading as these territories were often at war with one another or were battling over territorial borders. Egypt and Mitanni clashed over Syro-Palestine before Mitanni was defeated by the Hittite Old Kingdom's first king in the late 14th century BCE (Van de Mieroop 2016, p.174). The clash between Egypt and the Hittites over the same territory culminated in an Egyptian-Hittite peace treaty

in 1259BCE (Collins 2007, p.62). Assyria's and Elam's expansion and pressure on the borders of Babylon eventually led to its collapse around 1155 BCE (Van de Mieroop 2016, p.187).

The nature and extent of Hittite metal use is an enigma: it is known through the documents and texts of the region and its neighbours that metal was an important practical and ideological material: bronze weaponry for the "legendary Hittite army", and iron used to symbolize the monarchy (Chernykh 2017b, p.266; Yalçın 1999, p.182). The remains of these metals are archaeologically scarce in Hittite territory, though frequently found in Greece, Cyprus, the Levant, Iran, and the Caucasus.

The core Hittite territory was the northern half of the Anatolian central plateau but during the second half of the 2nd millennium BCE Hittite influence spread further south and southeast (Glatz 2009, p.129). During the Middle Hittite Period, one of decline between 1600 and 1400 BCE, the Mitanni had retrieved most of Northern Syria into its territories and continually threatened the Hittite borders. This was the case until the reign of Suppiluliuma I, at which time the Mitanni region was subdued and gradually absorbed into both the Assyrian and Hittite spheres (Bryce 1998, p.49; Van de Mieroop 2016, p.161). The Hittites soon had control of territories as far south as Damascus, but this brought them into conflict with Egypt, which also had interest in this region. Qadesh in the Levant was gained and lost by the Egyptians and the Hittites respectively until the Battle of Qadesh in the mid-13th century BCE. This battle concluded in a stalemate though both sides claimed victory (Collins 2007, p.54). During the battle the smaller state of Amurru switched its allegiance from Egypt to Hatti. The treaty drawn up is revealing of the nature of

trade during this diplomatic but belligerent period: Amurru, by the terms of the treaty was forbidden to trade with Assyria, or to allow Assyrian merchants access across their territory to goods arriving at the Eastern Mediterranean coast (Van de Mieroop 2016, p.178; Collins 2007, p.68).

During the 12th century BCE there was widespread upheaval across Southwest Asia and the Eastern Mediterranean, but regions were affected differently. The Hittite state disintegrated around 1200 BCE, its southern states falling into the hands of the Assyrians and many cities which had been previously abandoned on the Anatolia Plateau were destroyed (Van de Mieroop 2016, p.203; Collins 2007, p.78). The Assyrian domination of the region did not last long and the Assyrian Empire also declined during the 12th century (Van de Mieroop 2016, p.178). There was a shift toward increased nomadism in the Upper Tigris region after the collapse of regional, central authority (Ökse 2017, p.369). It is also during the 12th century that destruction of many coastal sites in the Levant occurred (Van de Mieroop 2016, p.178). The effect was less disruptive in the south in comparison with the north, with several sites showing evidence of continuity, possibly owing to settlements flourishing with the cessation of Egyptian imperial control (Killebrew 2013, pp.3–4).

Egypt and Mesopotamia survived, though affected by repercussions they both fell into decline shortly afterwards (Van de Mieroop 2016, p.203). Mesopotamia and Luristan appear to have been in contact from the 13th to 10th century (Overlaet 2005, pp.9–10). North Eastern Arabia also shows signs of decreasing interaction, with no imported pottery and only one variety of coarse, handmade, undecorated

ware (Magee and Carter 1999, p.163). The picture of Southwest Asia is one of diminishing contacts and a decrease in use of high-status goods.

The end of the 2nd millennium BCE sees migration into the region, including the movement of the Phrygians into Anatolia (Van de Mierop 2016, p.217). In the Northern Caucasus the migrations were not caused by people arriving in the region, so much as by widespread changes in settlement pattern – the mountainous regions were abandoned, and instead people settled in the piedmont valleys (Reinhold 2017, p.345), though Özfirat (2017, p.307) describes continuity in the region's settlement pattern. Collins (2008) summarises the various effects of the collapse of the Bronze Age in the final century of the 2nd millennium BCE:

“the fragile economic, social and political systems that had linked and sustained states across the entire region were irreparably damaged... the collapse of strong, centralised control led to reductions in trade, inflation, internal problems, warfare, piracy, banditry and dispossessed people”

However, not all regions were as starkly affected by the decline of central authority and international way of life. Though most sites on Cyprus were abandoned, those which survived continued to trade widely from the Levant to the Mediterranean (Knapp 2008, p.247). The effects of the Bronze Age collapse were more varied on Cyprus possibly owing to the lack of cultural unity across the island at this time, which therefore moderated the scope for political influence from mainland regions hoping to control it (Iacovou 2013, p.2). The Southern Caucasus also did not witness such large-scale destruction as much of Southwest Asia, but rather a gentle transition into the Early Iron Age, though there was a corresponding change in material culture indicating some form of technological or ideological shift (Smith

2005, p.267). For example, the Lchashen-Metsamor culture extended from the 15th to the 9th c. BCE, with clear continuity of material culture, though there were some accompanying transformations in technological traditions (Khatchadourian 2011).

Evidence regarding the continuity of major trade networks is vague, though Sherratt argues that inter-regional trade continued at the end of the 2nd millennium BCE in an altered and unknown format (2003, p.40). Van de Mieroop describes a scenario in which private merchants not royal centres continued after the collapse of the trading states and became leaders in trade (2016, p.217).

4.4 1st millennium BCE

The 10th century BCE marks the beginning of re-urbanisation, increased competitive trade, and more intense cultural interaction between many regions across Southwest Asia, most notably in Northern Mesopotamia with the ascent of the Neo-Assyrians (Grayson 1982, p.238). By the 9th century BCE the Neo-Assyrians were beginning military expansion into neighbouring regions prompting technological transfer and some overlap of material culture (Mazzoni 2010, p.22). Indeed some of the only evidence to come from the Neo-Elamite period in Iran relates to the impact of Neo-Assyrian expansion on the region rather than providing direct information about Elamite life itself (Alvarez-Mon 2013, p.471).

In contrast to Assyria Mesopotamia was economically and politically weak as well as culturally isolated owing to disruption of access to trade routes (Brinkman 1982, pp.282–3; Fales 2010, p.29; Van de Mieroop 2016, p.211). The indigenous Babylonians occupied the region alongside two other cultural groups; the nomadic

Aramaean tribal groups and the sedentary Chaldeans. The Arameans had been pushed southwards from Northern Mesopotamia by the Assyrians in the 11th c. BCE and had a destructive presence on the land and its inhabitants (Fales 2010, p.33). The Chaldeans were engaged in large-scale agriculture and were eventually responsible for improved trade along the Persian Gulf (Brinkman 1982; Fales 2010; Collins 2008). Trade was conducted through Southern Mesopotamia in the early 1st millennium BCE despite the lack of Babylonian access to it, as it was certainly accessible to the Chaldeans. Evidence for this is found in the list of goods sent as tribute to Assyria containing imports from the Levant, Northern Arabia, and Egypt (Fales 2010, p.37). Eventually the Arameans also ceased to be enemies of Babylon as the two groups joined forces against the Neo-Assyrians, which allowed better Babylonian access to trade along the Euphrates as well as access to Arabian goods (Brinkman 1982, p.288).

Chernykh (2017a; 2017b) describes the Caucasus as a 'bridge' in the 1st millennium BCE, as opposed to the previous millennium during which the mountains had presented a 'barrier' between the Eurasian Steppe and Southwest Asia. Scythian horsemen of the steppes moved south and occupied the same region of the Northern Caucasus as the Maikop Culture over two millennia earlier, but once again the region shows no evidence of local mining or metalwork production, despite reliance on metallic objects, suggestive of renewed contacts with the Southern Caucasus (Chernykh 2017a, pp.488–9). At the end of the 8th c. BCE the Northern Caucasus once more display signs of a decrease in settlement size and number (Reinhold 2017, p.345).

The period is one of gradually increasing contacts: there is evidence of trade between the Southern Caucasus and the Greeks at Corinth and Miletus, with even potential trade east indicated by some Chinese silk at Toprak Kale (Barnett 1982, pp.366–7). However there were also political struggles: south of the Caucasus to the north of Assyria (from eastern Turkey, to northwest Iran, northeast Iraq, Iranian Azerbaijan, Armenia, and parts of the southern Caucasus) the Kingdom of Urartu frequently clashed with the Neo-Assyrians over territory, especially over Northwest Iran (Castelluccia 2017a, p.400; Danti 2013, p.328; Barnett 1982, p.322; Dan 2010, p.331). Presumably this was in part owing to the rich metal sources in the region (Barnett 1982, p.327; Van de Mieroop 2016, p.217; Akcil 2006, p.91), a theory further supported by the Urartians seizure of the metalworking region of Metsamor after the 8th c. BCE (Barnett 1982, p.366). There is clear evidence of use of seasonal roads and tracks at this time, which had also been fortified indicating both a great focus on, and the high stakes of, trade (Danti 2013, p.332).

It is surprising that the same resource-rich regions should still have been so highly fought over, since the majority of tools and weapons in Urartu were now made of steel (Yalçın 1999, p.185), and iron is a much more widely available resource. This availability of ore is often cited as the motivation behind the adoption of iron metallurgy (Pickles and Peltenberg 1998, p.68). However, it has been suggested that iron ores were discovered accidentally through copper sulphide smelting (Pickles and Peltenberg 1998, p.79), and there is evidence of copper smelting sites which went through a transitional iron smelting period in Cyprus and Palestine (Waldbaum 1980, p.89). In the Southern Caucasus the iron ores exploited were present in regions where chalcopyrite had been the dominant copper-bearing

mineral (Erb-Satullo *et al.* 2014, p.155). Therefore, it is possible that the same political struggles over resource-rich land could have continued into the Iron Age until the discovery of the abundance of iron ores across the region. On the other hand Erb-Satullo *et al.* (2014, p.160) state that iron smelting sites and copper smelting sites in the west of the Southern Caucasus were not found in close proximity to one another, suggesting either a separate regional tradition, or the use of different ore sources of both metals.

There appears to have been a level of communication between the Southern Caucasus and Northwest Iran in the early 1st millennium BCE as they shared some similarities in grave goods and metal objects (Castelluccia 2017a, p.393). The most striking class of objects shared by both regions are 'bronze bells', which are characteristic of Early Iron Age Southern Caucasus (*ibid.* p.400). These bells are also commonly found in Urartu and Assyria, indicating the influence of the Southern Caucasus on southern regions during this time (Castelluccia and Dan 2014, p.98). At the same time the Southern Caucasus was trading with the Northern Caucasus, as evidenced by the characteristic bronze belts found at the cemetery at Tli (Zischow 2017, p.411). Though Assyria, Urartu, the Southern Caucasus, and regions of Iran clashed over territory, there appears to have been continued communication and trade of goods through these regions, perhaps by nomadic tribes disassociated from regional war, or possibly shared material culture may represent the collection of war booty or tribute.

Despite cultural and political fragmentation in the late 2nd millennium BCE, the Southern Levant continued to flourish through trade from the 10th century to the 8th century BCE, after which it was disrupted by Assyrian expansion (Killebrew

2013, p.2; Mitchell 1982, p.448). Before this disruption, however, increased use of iron in Assyria from the 9th century BCE indicates trade between the Southern Levant and Assyria, as the Philistines cornered the market in iron technology (Mitchell 1982, p.449). The mines at Timna, though no longer under Egyptian control after the 12th c. BCE, had continued to be exploited by local craftspeople and show evidence of having been intensively exploited again, suggesting a level of economic continuity (Rothenberg 1972). Phoenician harbour cities of Tyre, Sidon, Byblos, and Arwad continued to function owing to maritime skills, though they were less wealthy than in the preceding period (Van de Mierop 2016, p.220). Far-ranging eastern Mediterranean trade was often been interpreted as “a direct function of Neo-Assyrian imperialism”, but as the Neo-Assyrians experienced a period of decline during the peak of Phoenician trade with the Western Mediterranean, this is no longer seen as likely and the regions are considered to have been connected but with no form of power imbalance (Fletcher 2012).

Muweilah, a site in Southeastern Arabia, was constructed in the 10th century BCE and indicates change based on certain developments: the dual effect of *falaj* irrigation (the method of transporting water long-distances underground) and the domestication of the camel (Karacic *et al.* 2018, p.27). These developments allowed for settlement further from oases and the coastline (Magee 2004, pp.24–5). The domestication of the camel also enabled the transport of goods across land, rather than only along the Gulf by boat; this new method of transport opened up the opportunity for wide-scale intra-regional trade across the entire Arabian Peninsula. Western Arabia therefore became more active in the 1st millennium BCE, and began to take part in trade with the Levantine Coast and Greece

apparently leaving Southeastern Arabia relatively isolated from Southwest Asia (Mazzoni 2010, p.20). However there is evidence of potential trade in ceramics with Mesopotamia, Pakistan and the Fars region of Iran (Magee 2004, p.41; Magee 2013, p.496).

The Neo-Hittite states in Anatolia and Syria fall slightly outside the scope of this thesis, as the re-emergence of state centres in the region did not occur until 700 BCE (Hawkins 1982, p.372). The Central Plateau is described as going through a 'Dark Age' but the sites which remained occupied show evidence of continuity from the Late Bronze Age (Kaelhofer *et al.* 2009). The region was made up of small, independent, ethnically diverse polities with a shared material culture clustered around the northeast corner of the Mediterranean Coast and continued thus throughout the early 1st millennium BCE until annexed by the Neo-Assyrians at the end of the 8th century BCE (Osborne 2013; Osborne 2015). Despite the region's political obscurity, Syro-Anatolian polities were trading with the Aegean, leading Osborne to place economic motivation behind Assyria's conquering interest. Luristan also appears to have been isolated during the early 1st millennium BCE, as there are no imported ceramics but a strong local pottery tradition (Overlaet 2005, p.12).

We can broadly separate Southwest Asia into two distinct trading regions throughout the early 1st millennium BCE, though they are not wholly separate from one another, and have evidence of contact mainly through the Neo-Assyrian Empire. The first group of regions which are frequently in contact are Assyria, Urartu, the Southern Caucasus, Northwest Iran, and Elam. Many of these regions display a continued interest in tin-bronze objects and metal-rich regions of the

highlands. The second group of regions in contact with one another includes Cyprus, west and north Arabian Peninsula, Egypt, Greece, and other western Mediterranean areas, and these appear to operate mainly through the Phoenicians of the Southern Levant however there is a dearth of evidence with which to draw conclusions. Until 700 BCE Mesopotamia, and West and Central Anatolia were under-developed and isolated from regional interaction, as to a certain extent was Eastern Arabia.

5 Chapter Summary

Metallurgical development over time	
11th millennium	Use of 'greenstones' in pigments, jewellery and ritual artefacts
8th millennium	100 native copper objects found at Çayönü Tepesi in Anatolia. Native copper from Aşliki Höyük (Anatolia), though 3 contain >1% Sb therefore possibly alloys Earliest native copper object found in Iran Possible lead beads found at Çatalhöyük (Anatolia)
7th millennium	Possible tin-bronze object found at Konya (Anatolia) and slag fragment found at Çatalhöyük (Anatolia)
6th millennium	Two tin-bronze objects found: 1 from Tel Tsaf (S Levant), 1 from Aruchlo I (Georgia); and an unsecurely dated lead object Lead object found at Yarim Tepe (Iraq) Unsecurely dated smelting evidence (hundreds of crucibles) found at Tal-I Iblis (Iran)
5th millennium	Earliest securely dated large scale smelting operation evidence found at Belovode in Serbia Presumed widespread adoption of smelting technology across Southwest Asia owing to artefacts and smelting debris and equipment found
4th millennium	Complex and unique hoard of copper-alloys found in various locations in the Southern Levant Move to use of furnace-smelting rather than crucible-smelting Experimentation with polymetallic ores widespread
3rd millennium	Smelting technology appears in Eastern Arabia Tin-bronze technology presumed widespread Kestel mine debated to be exploited for tin

Figure 7: Summary of technological development by archaeological evidence from the 11th millennium BCE to the end of the 3rd millennium BCE, as discussed in section 2, this chapter

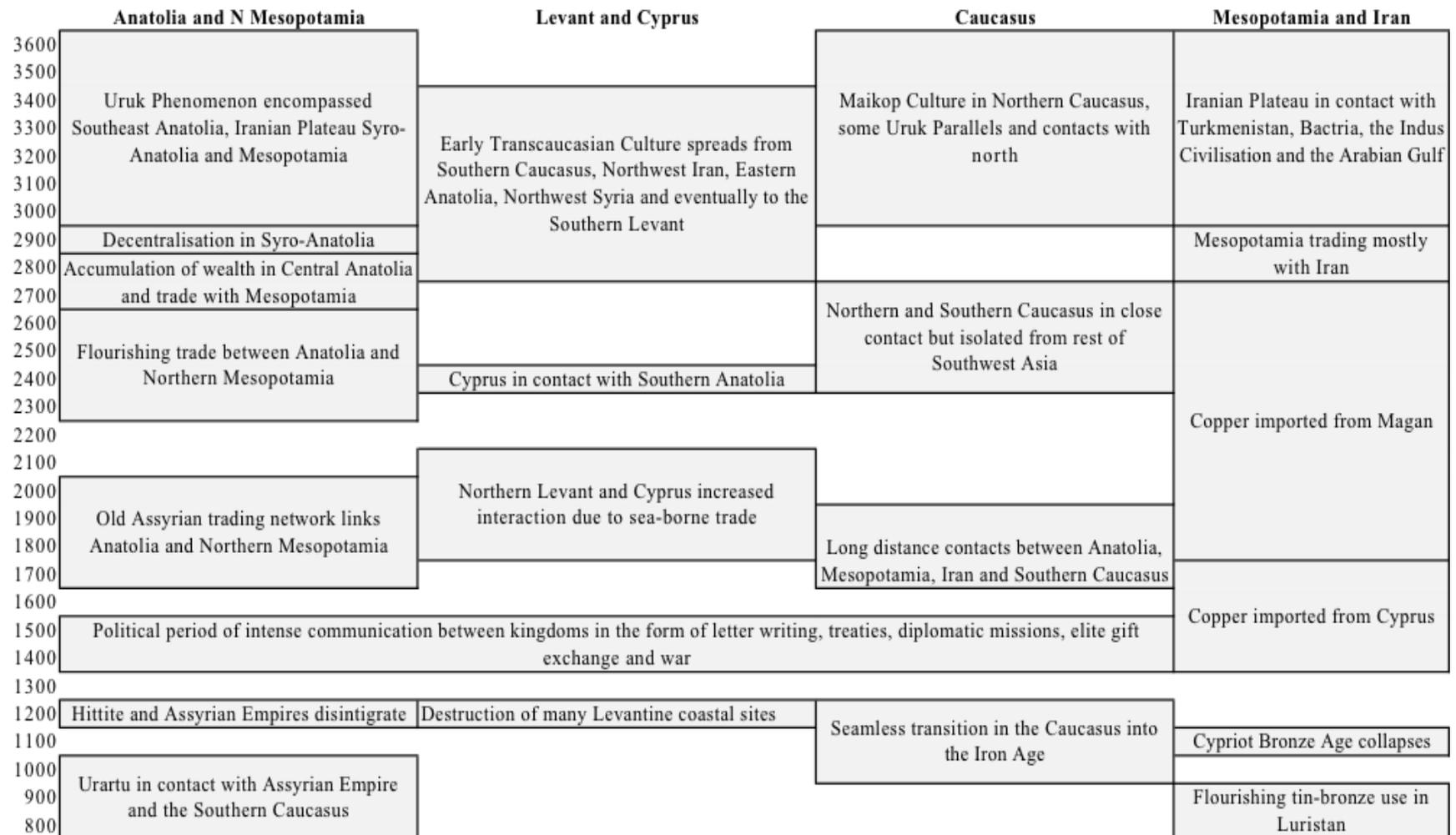


Figure 8: Rough summary of regional interaction and cultural developments from the mid-4th millennium BCE to the early 1st millennium BCE as discussed in section 4, this chapter

Chapter Three: Data and Analytical-Interpretive Methodology

This chapter covers the collection, adaptation, and use of the database of chemical data from Southwest Asia used in this thesis. It provides a summary of the analysis by time and region, followed by a brief discussion of the obstacles that it was necessary to overcome before pre-processing: the legitimacy of using data generated with a wide range of analytical procedures, the challenges and choices in the treatment of chronology and the categorisation of regional zones. The details of these analytical-interpretive methodologies and their application to the study of archaeological metalwork from a range of regions and periods are outlined in the final sections of this chapter.

1 The database

At the core of the project is a database of 9,838 chemical analyses collated from 105 publications and incorporating several existing data sources (including those of Cuénod 2013 and Krause 2003). This database is a more or less complete survey of published analytical research on archaeological metalwork from across Southwest Asia. Nevertheless, even a cursory glance at the data, organised by

region and time period (Table 1), reveals that the distribution of data is far from consistent across either space or time. In all cases throughout the subsequent results and discussion chapters the size of relevant regional and chronological assemblages is highlighted carefully. This is an essential step when many of these datasets remain unreliably small. Though they are often included for completeness, they are typically displayed as unreliable by the use of hatched lines or other markers.

Table 1 distribution of artefact data by geographical region and time period (exact dates for each time period discussed in section 2.2, regional boundaries discussed in section 3.1)

	W and C Anatolia	Med Coast	Cyprus	S Levant	E Anatolia	S Cauc	N Cauc	N Mesop	Mesop	W Elam	Louistan	Caspian Coast	E Arabian Peninsula	Kerman	Total
Late 5th	2	0	0	0	0	25	0	3	0	0	0	5	0	2	37
Early 4th	20	21	6	86	4	17	0	4	0	68	0	33	0	2	279
Mid 4th	10	0	0	0	1	6	0	24	66	0	1	7	0	17	135
Late 4th	44	15	0	9	39	40	92	18	5	28	3	47	0	3	375
Early 3rd	74	2	0	29	162	18	0	8	72	13	9	4	0	32	423
Mid 3rd	289	56	31	40	21	634	180	65	101	123	55	0	47	37	1680
Late 3rd	299	70	93	106	10	85	25	190	1316	44	36	101	262	63	2701
Early 2nd	16	87	214	31	2	60	14	59	213	19	60	53	67	1	1079
Mid 2nd	209	118	62	503	49	84	51	10	6	35	23	24	47	32	1272
Late 2nd	0	0	26	43	0	61	106	12	5	20	31	78	35	0	417
Early 1st	0	0	1	22	22	391	52	123	6	0	349	51	220	1	1241
Mid 1st	0	0	0	4	0	29	1	4	41	1	17	17	0	3	118
Late 1st	13	0	0	0	0	18	0	8	2	0	1	0	0	12	54
Total	988	369	433	873	311	1472	521	529	1834	351	585	420	678	211	9838

This is, in part, due to an unevenness of metal finds across this vast region, but its structure also reflects a palimpsest of individual academic interests built up over more than a century of research. The initial database contained data obtained not only from metals, but also from ore, slag and crucible fragments, as well as numerous duplicate analyses. Wherever possible, these have been identified and removed from the ‘final database’ used in this thesis; the criteria for removal are outlined specifically below. Another key issue was variability in the character and quality of our analytical data. To some extent, as Cooper and Green (2016) pointed out, all datasets are *characterful*, and if we set out to maintain a diverse approach

to legacy data we must both accept and accommodate this *characterfulness* in our treatment and interpretation of them.

A degree of quality control is essential to ensure that identified patterns within the data can be explored with confidence and to militate against the most problematic data sources. It is also necessary to overcome basic inconsistencies in notation and object description, as well as to establish a coherent chronological framework within which to conduct this research. These challenges are discussed in turn below.

1.1 Data quality

Data quality is perhaps the biggest issue facing this thesis. It is also the least easy to address. From a certain perspective, a fully 'hygienic' database of recent analyses for which data quality has been carefully recorded and controlled is the only solution. Yet, given the aims and scale of this project, this hardly presents a practical solution. Existing analyses at this gold standard are few and far between and repopulating even the current distribution with new analyses would require decades of well-funded analytical research and the negotiations for re-sampling (in the face of curatorial concerns, institutional issues, and major geo-political barriers) would likely render it impossible. I would argue that it would also be a phenomenal waste of earlier resources and efforts.

1.2 Comparability of analytical techniques

Once we accept the logic of accepting all but the most problematic datasets, it is imperative to ensure an adequate level of cohesion and comparability across the range of analytical techniques which have been employed over the history of archaeometallurgical research. The first step in this endeavour is to acknowledge, in general, the frequency with which the different techniques were used in specific analytical traditions, research programmes, and laboratories in particular. Past investigations on inter-laboratory consistency and analytical technique compatibility have suggested that with the exception of certain techniques and trace elements, such as OES and measurement of lead (Hughes 1979), it is mostly possible to compare results from different analytical instruments. For a full description on inter-laboratory and analytical technique comparisons see Pollard *et al.* (2018), the following section contains summaries of only the most relevant comparisons of data to the integration of large datasets.

After a single set of objects was analysed by twenty two laboratories, Northover and Rychner (1998, p.31) concluded that the analytical methods analysed (wet chemistry, direct current plasma spectrometry, ICP-OES, AAS, ED-XRF, EPMA, PIXE, and NAA) provided data which could be “used interchangeably with other data”. Pernicka (1986, p.26) found that the “Stuttgart analysis by emission spectroscopy agree well with analysis performed in Heidelberg by NAA and AAS” on the same objects, but that there were discrepancies in the amounts of Ag and Au. Ten years later in a similar study Pernicka *et al.* (1997) found that the results on a large set of objects analysed by NAA and OES (conducted in Heidelberg and Moscow respectively) agreed within a factor of three when the minimal detectable

level for both techniques was also taken into consideration. This study also found a discrepancy in lead concentrations, however, when new results (NAA) were compared with old (OES). Cuénod (2013, pp.139–147) compared data from individual sites (Tepe Hissar, Selme, and Susa) as well as general Mesopotamian data, which had been analysed by more than one method (OES, PIXE, XRF, AAS, ICP-OES, and spark-source mass spectrometry) and in various laboratories. She found that there was general agreement, though automated methods of analysis ought to be avoided (such as Principle Components Analysis and Cluster analysis) as there are clear differences in precision, accuracy, and detection limits (*ibid.* p.146).

Breaking the data down further reveals not only the gradual development of instrumental techniques but also a preference for certain techniques` within certain laboratories as well as the broad foci of their research (Figure 9 to Figure 14). It is clear that there are important regional patterns in the application of analytical techniques. The analysis of Mesopotamian and Assyrian objects, for example, has been conducted primarily with X-Ray Fluorescence spectrometry (XRF) (Figure 11 and Figure 13), whereas the majority of data from Caucasian metalwork was obtained using Optical Emission Spectrometry (OES) (Figure 10). Clearly, such regional dominances have the potential to create patterns of difference across space that have more to do with the detection levels, precision and accuracy of the techniques used in the analysis than from archaeologically significant differences in human sociotechnological behaviours of the past. We must remain conscious of these potential effects within our analysis.

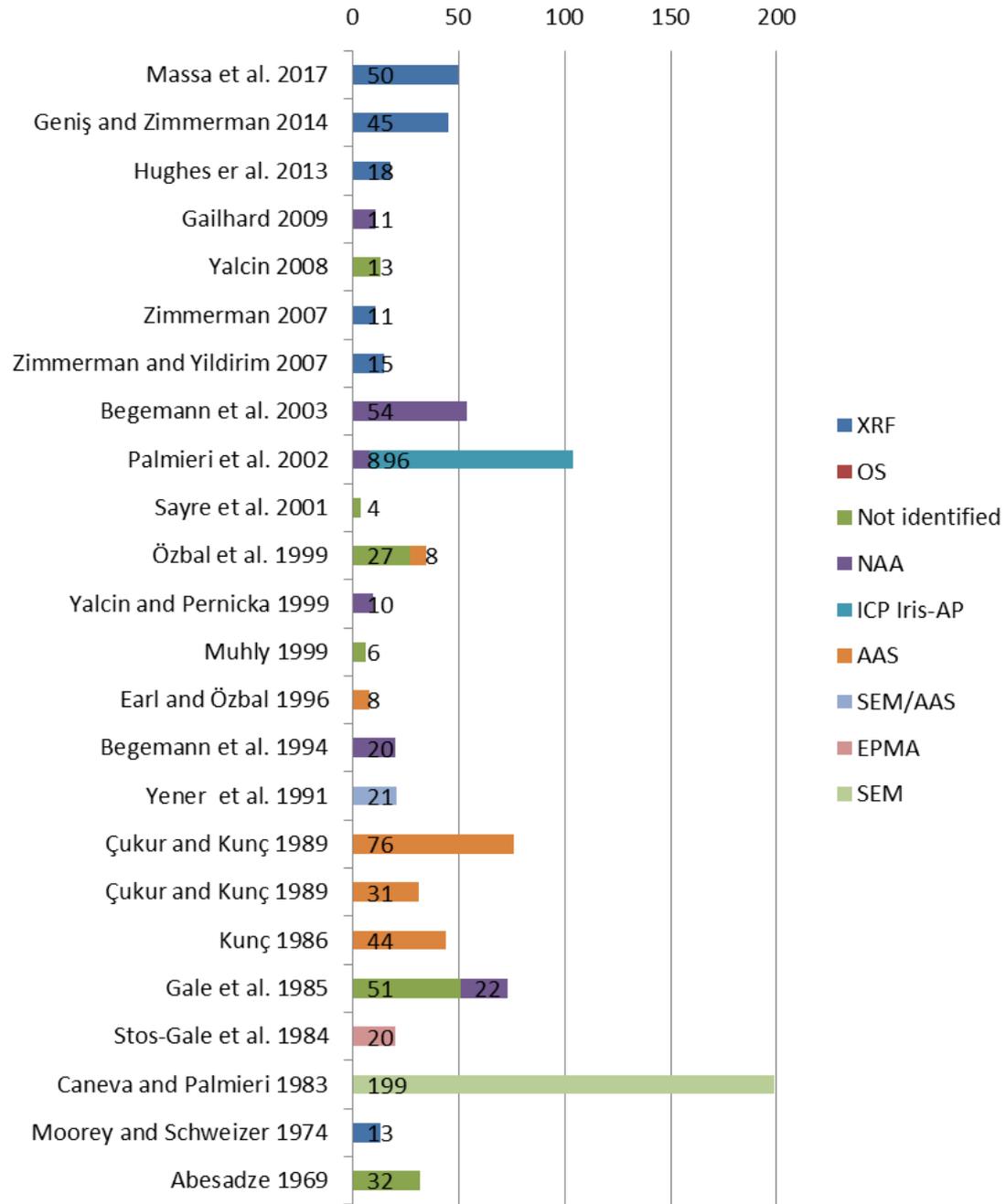


Figure 9 Anatolian chemical data by author and separated by analytical technique

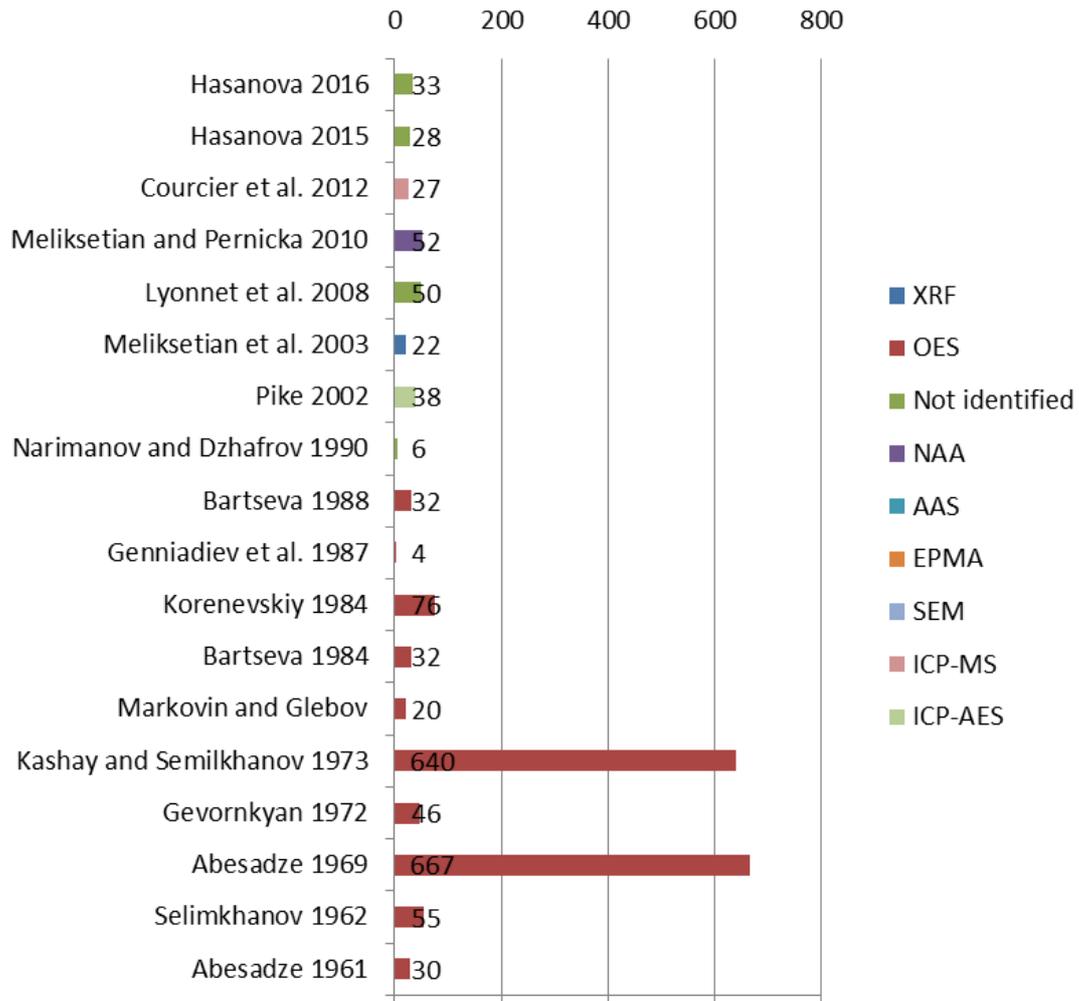


Figure 10: Caucasus chemical data by author and separated by analytical technique

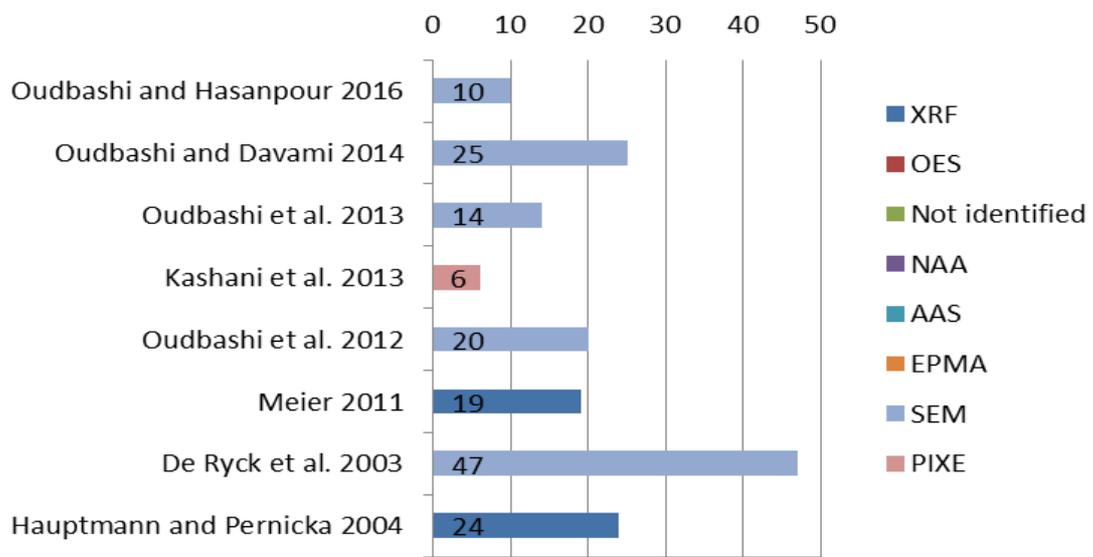


Figure 11: Iranian and Mesopotamian chemical data by publication and separated by analytical technique

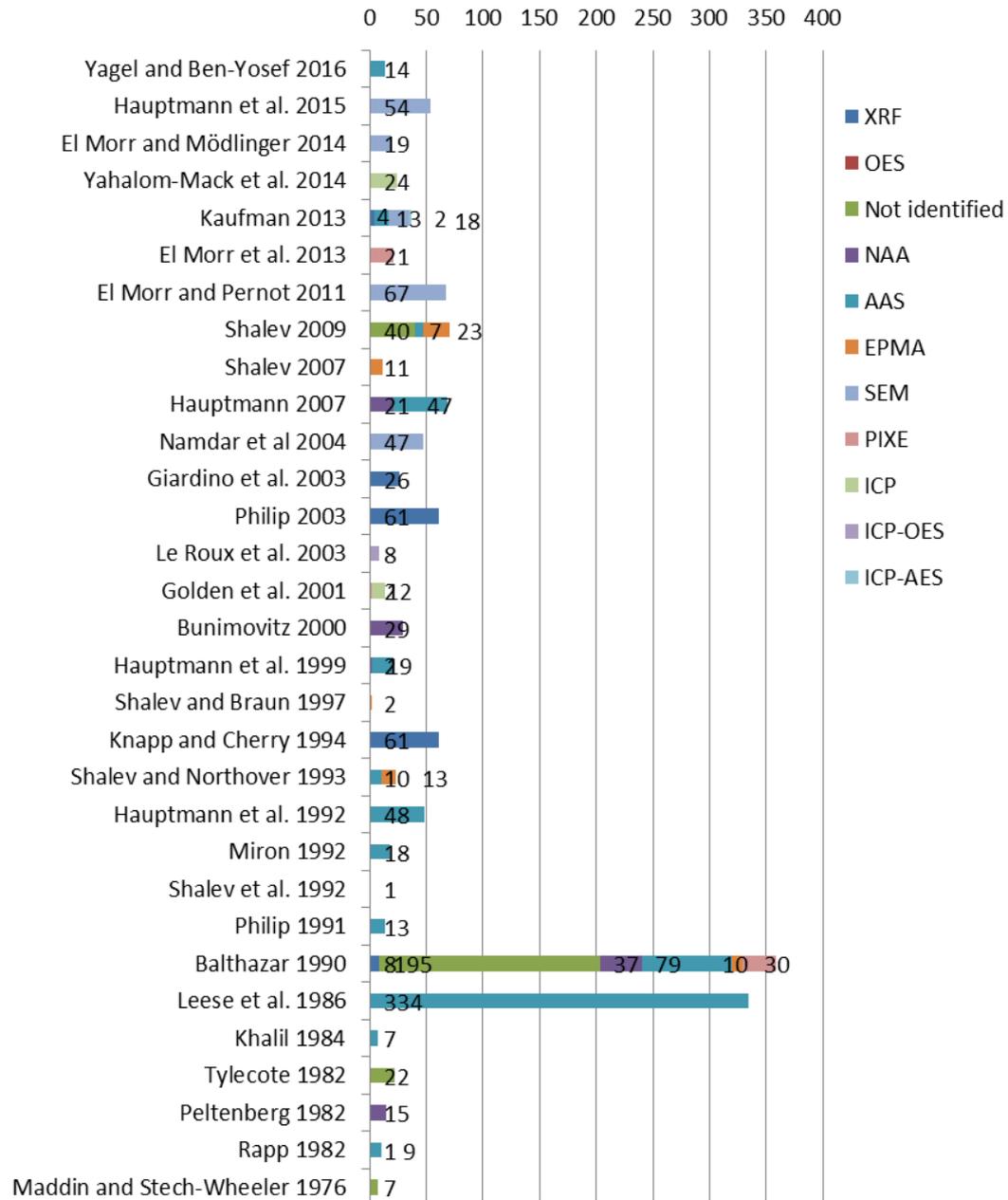


Figure 12: Levantine chemical data by publication and separated by analytical technique

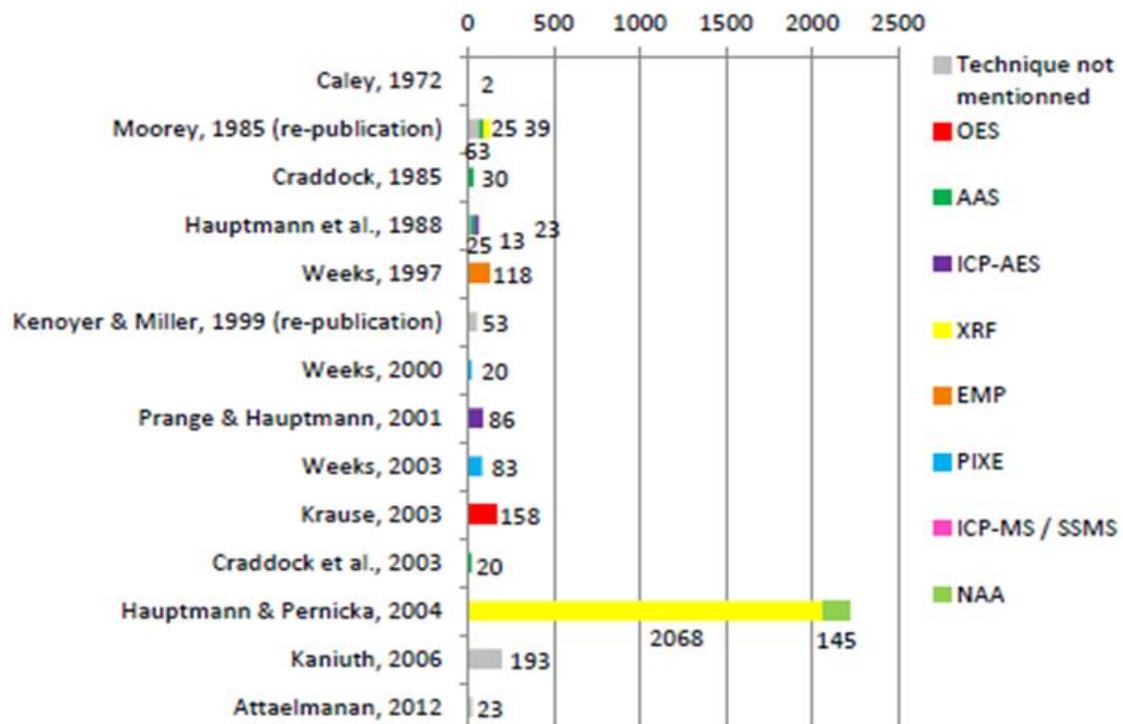


Figure 13: Chemical data by publication and separated by analytical technique from Oman, Bactria, Indus Valley and Mesopotamia (Cuenod 2013 84)

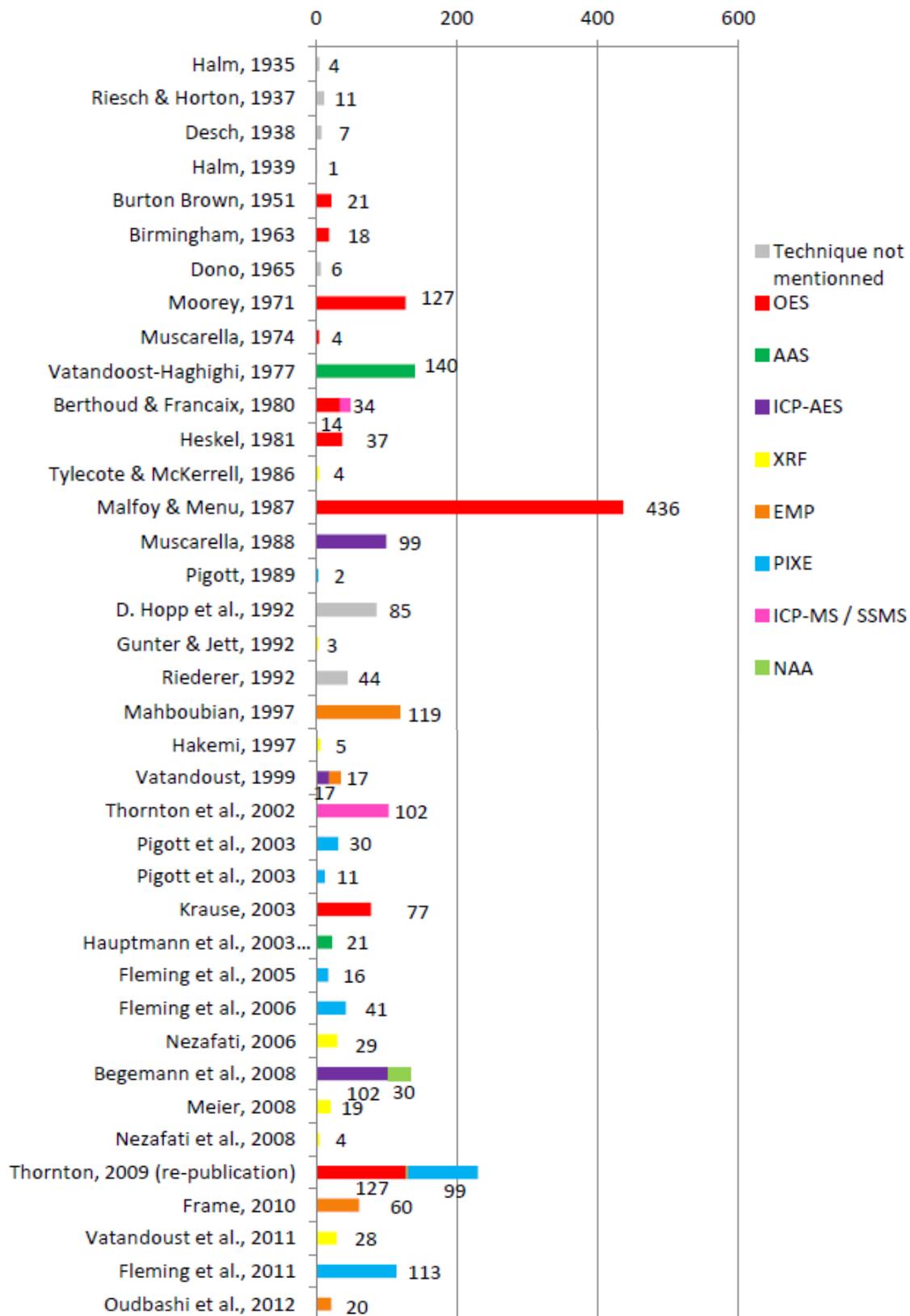


Figure 14: Iranian chemical data by publication and separated by analytical technique (Cuénod 2013, p.83)

An example to highlight the possible problems of variance in analytical technique is shown in Table 2. This table depicts the compositional data for a single analysed artefact analysed by both EPMA and NAA a year apart (Stos-Gale *et al.* 1984; Gale *et al.* 1985). The differences are mostly minimal, and nickel is identical in both analyses, however the varying quantities of recorded antimony is sufficient to alter which copper group the object falls into (based on the presence or absence of As, Sb, Ag, and Ni, discussed in detail in section 4) as the cut-off between presence and absence is 0.1%. Therefore the choice of analyses kept within the ‘working’ database may have a significant impact on the conclusions drawn if applied to a significant number of analyses.

Table 2: example of differing analytical results on the same object, conducted by the same authors, but with differing techniques

Number	Type	Method	Cu	As	Sb	Ni	Ag	Sn	Authors
11811	Flat Axe	NAA		1.64	0.1302	0.03	0.059	4.53	Gale <i>et al.</i> 1985
11811	Flat Axe	EPMA	92.6	1.35	0	0.03	0.08	5.19	Stos-Gale <i>et al.</i> 1984

Further discussion of duplicate data management can be seen in the following section. In the case of these two papers and analyses represented in in Table 2, the 1984 EPMA analytical data was removed from the database. The reasoning behind this decision was that they represented the only use of EPMA analytical techniques in the Anatolian database and was only very rarely used in other regions of Southwest Asia - the logic behind this being to enable more efficient database cohesion and compatibility.

1.3 Duplicate data

If the chemical composition of a specific object or set of objects is recorded more than once within the database, it has the potential to significantly skew the results of our ubiquity analyses². This is most problematic, but perhaps most easily resolved, when significant blocks of data are (re)published in separate sources. However, even single artefacts can be a problem, especially when we are interested in the emergence and spread of new alloying recipes and technologies. Rare cases of early brass, for example, are widely reported in the literature and could easily be unevenly duplicated in the database, lending weight to one region's use of zinc over another's. As far as reasonably practicable, duplicate data must therefore be removed, but as highlighted in section 1.3 of this chapter, the choice of which data to remove may have manifest consequences to the results of data interpretation and must be approached systematically as far as possible.

Duplicate data here refers to (1) objects that have been analysed during the same study but in multiple locations on the object, generally by SEM, (2) identical object data produced by one analytical study but published repeatedly, or (3) objects that have been analysed more than once by different analysts, laboratories, or techniques. The first is the simplest type of duplicate data to rectify as they are presented in the same publication - an average of each element is taken from all datapoints located on one object. The largest example of this type of duplicate data

² A dagger and a rivet from that dagger do not count as duplicate data, even though they might be made from the same metal, because they have been separated and treated differently- as two daggers made from the same metal are considered two separate items - they have been treated and approached separately - as with a dagger and its sheath.

was the Late Chalcolithic and Early Bronze Age copper objects from Arslantepe analysed by SEM (Caneva and Palmieri 1983).

The second type of duplicate data is not quite as simple as it sounds. The two papers discussed earlier presenting varying Trojan data was simple enough to choose between owing to the traditions of instrument use throughout the database. However, by far the largest example of this kind of duplicate data was that of 743 objects contained in both Krause (2003) and Esin (1969). The data in Esin matches a gap in the numbered sequence of the analytical programme undertaken in Stuttgart by Junghens *et al.* (1960), which suggests that the analyses were conducted at the same time, and as part of, the SAM project. However, this Anatolian sequence was not mentioned in the original publication. Another indication that the analyses were conducted by the Stuttgart group is that Krause (2003) does not list Esin's work as a bibliographic source for the data, suggesting that he transcribed the original laboratory records. It is possibly due to a linguistic issue, but there are discrepancies between some object typologies, and a problem of archaeological tradition from two separate countries that has resulted in differing chronological periods. Unexplained, however, are the discrepancies between elemental composition, though fortunately they are rare.

Contextual, and possibly linguistic, discrepancies include: "*Lituus*" in Esin, which was often but not always "hook" in Krause; "speartip" and "Palmela arrowhead" were interchanged; and "winged axe" varied between "flat axe" and "flat adze". These are not major differences but highlight inconsistencies of perception and categorisation of the same objects dependent on either author or time of research. The perception of the analyst or author has an eventual effect on typological

categorisation – a *lituus* has symbolic significance, a hook does not. Though the publication by Esin could probably be regarded as more accurate in terms of knowledge of regional context and chronological classification owing to her expertise in Anatolian metallurgy, the decision was made to follow Krause. The duplicate data only accounts for half of the Anatolian data from the SAM database, meaning a change in description and context would create a less easily comparable dataset. If there are discrepancies between Krause (2003) and the source materials used for that database, then the aim here is to have consistent discrepancies.

The third type of duplicate data was the most complicated, as already discussed, as different analytical instruments or analysts can produce different results from the same material. Though the effects of these differing results may be minimal it is still necessary to choose which shall be included. The following two decisions were made in this order wherever there were competing analyses.

- 1) prioritise analyses reporting the four diagnostic elements As, Sb, Ag, Ni used by the Oxford System (see section 4)
- 2) if it is a choice between two distinct instrumental techniques – choose the technique which is more common within the regional database so as to maintain maximum comparability

1.4 Inconsistent notation

Comparison between datasets is hindered by the lack of standard practice in publishing scientific reports. Annotations such as “tr” (trace), “det” (detected),

“nd”, and “-“ are frequent in the articles containing data, however they are only sporadically clarified in the text. Though often these do not pose an obstacle the notation “nd” is frequently used in different ways. It can mean “not determined” (i.e. not looked for) or “not detected” (i.e. looked for but not present); the conversion of both of these into a 0 would be a problem, as it is only applicable to the second example.

Where the author has not clarified which abbreviation they have chosen to use, there is significant potential for problems with the inter-comparability of the data. In such cases, it was necessary to review both the house styles of individual publishers and other publications by the same authors in search of standard patterns of reporting described more fully elsewhere. Where this research was unable to clarify the position, “nd” was generally taken to mean ‘not detected’—the more common abbreviation— and substituted with a 0. However if “nd” occurred alongside “-“ or “0” it has been interpreted as “not determined” and left blank. A dash in the place of a number provides a very similar problem and has been treated in the same way.

Notations regarding the minimum detection limit are similarly used without explanation: “bdl” (below detection limit), “udl” (under detection limit), “<LOD” (less than limit of detection), “ul” (under limit). The detection limits themselves are rarely included in the literature. Without knowing the detection limit, therefore, it was impossible to represent these notations in an accurate numerical form. Instead the ‘Minimum Reliable Limit’ was used (Perucchetti, *personal communication*). For each individual dataset produced by one analyst, the lowest recorded quantity for each element was noted and halved. For example <0.1

became 0.05, <0.05 became 0.025, <0.001 became 0.0005, and so on. This method was also used when elements were presented in the published data as 'less than' a certain quantity, and "tr" was indicated. Though this method of dealing with inconsistent notation is not an accurate representation of the data, it is sufficient for the purposes of this thesis, which deals mostly in the presence or absence of an element at greater quantities than these. For further discussion see Pollard *et al.* (2018).

2 Chronology

2.1 Cross-regional chronological sequences

A comprehensive chronology is fundamental to any archaeological research as it forms the backbone by which any context is linked to another. Approaches to chronology encounter several problems, the first of which is societal concept of time which is often culturally biased (Agrawal *et al.* 2004; Lucas 2015). Another obstacle frequently invoked is the socio-political history of the regionally separate archaeological disciplines and the effect this had on their development. Though there are many such global instances, in this section we will look at the Western European model of archaeology and that of the former Soviet Union as described in the 1980s. In trying to separate abstract and substantial time (objective and subjective) Shanks and Tilley (1987) described objective time in terms of capitalism as it was broken into measurable units which were considered separate from events, as opposed to subjective time which is time that was perceived by societies living within it. Trigger (1984) on the other hand described the

archaeology of the former Soviet Union as inextricably linked to the five stages of socio-economic evolution outlined by Marx. Since the 1980s it has been accepted that though separate regional archaeological disciplines may have their foundations in such political routes, they are not bound by them: Lindsay and Smith (2006, p.174) state that after the death of Stalin, before which there had been a vast accumulation of data for forty years, there was “renewed commitment to objectivity and a retreat from subjective authority imposed by state directives”. Though the collection of data had its foundations in a controlled narrative, it was then later synthesized on a large-scale and the biases of the previous period erased.

A parallel example which had a major influence not only over the Mesopotamian and Ancient Greek archaeological narrative but that of neighbouring regions, such as Anatolia which were considered ‘peripheral’, is embedded in the colonial and Empiricist past of Western Europe (Özdoğan 2007, p.18; Crawford 1991). These narratives are largely being addressed, however the language is so pervasive it has as yet been less successful. The 19th century AD ‘Three Age System’ and its position within Industrial Evolutionism of the time, has now largely lost its original meaning, and the Ages themselves are more or less empty terminology through which to place a relative sequence of events (Lucas 2004). These examples are by no means the only ones in the study of archaeology but are relevant to the current discussion of chronology. Undeniably socio-political ideologies have at times driven strands of archaeological research and this may in turn have influenced areas of research focus, possibly leading to slight imbalances in the distribution of excavated research areas. However the inability of modern archaeological

disciplines to disassociate from their ideological or political past is no longer a relevant concern in the construction of chronology.

It is possible that one way in which regionally based archaeological study is still affected by past ideology is largely due to linguistic barriers: if the academic discourse on such theories remains unavailable to a current researcher, they are perhaps unwilling to trust that it has been incorporated into modern approaches. Another linguistic barrier is the development of separate terminology and a disassociation of researchers in one discipline with those labels of another, despite the existence of broader terminology. Period0 represents a collaboration of researchers and modern technology which allows integration of archaeological and historical periods (www.perio.do/en 2018). Unfortunately it was not until too late that this resource became known to me, and synthesis of the Southwest Asian chronology was conducted more broadly for the purposes of this thesis.

It would be impossible to study 'the Early Bronze Age of Southwest Asia' as a unit and draw conclusions based on inter-comparison, as these periods occurred at widely varying times across the sub-continent. Rather the focus must be on the actual dates (or rather a possible range of dates) at which metallurgical traditions changed, thereby avoiding pre-constructed ideas of metallurgical innovation and the inevitability of the trajectory - despite a lack of adherence to the original meaning of the 'Three Age System' it still invokes the image of progress and an evolutionary narrative and an attempt has been made to avoid this (Lucas 2004, p.51). Figure 15 is an amalgamation of chronological schemes from the literature and an attempt to place these within a single chronological framework—although closer regional scrutiny often incurs disagreement over the exact dates at which

chronological periods ended or began, an attempt has been made to follow the general consensus of dates in each case (Palumbi 2012; Badgalyan *et al.* 2003; Yakar 2011; Sharon 2013; Cuénod 2013; Weeks 2003; oi.uchicago.ed 2016; www.britishmuseum.org 2016). Unfortunately it was not always possible to avoid dependence on 'Ages' when entering object data into the database. Where actual dates were given they were entered, but often objects were given context by 'Age'. In those cases the regional 'Age' dates from Figure 15 were given, but it means that many objects, though not *named* Early Bronze Age, are still allocated by reference as such. However if the absolute dates for the relative chronologies are ever substantially updated, it will be possible to reallocate the objects based on up to date archaeological research.

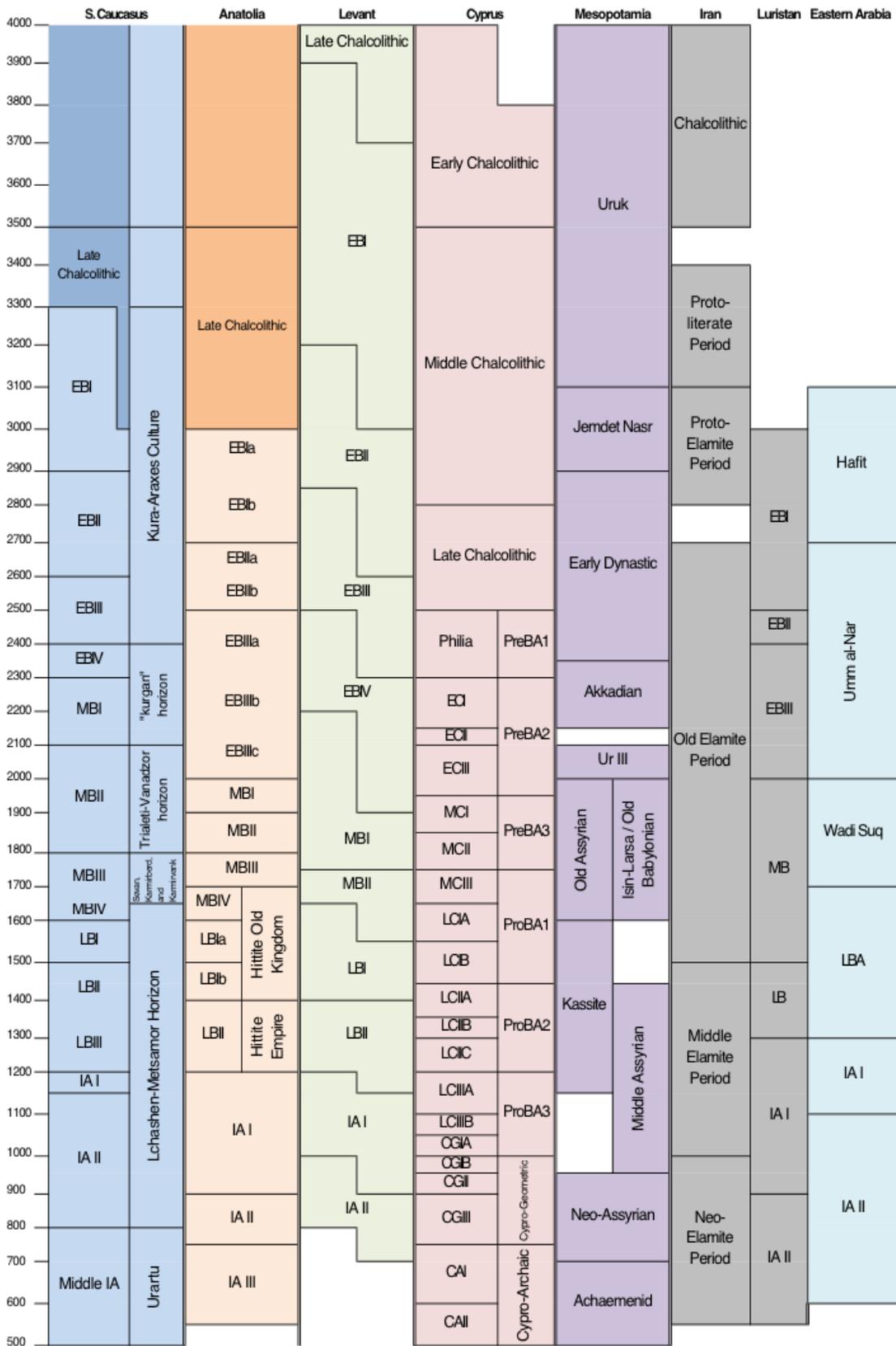


Figure 15: chronological sequences from the different regions of Southwest Asia (Palumbi 2012; Badgalyan *et al.* 2003; Yakar 2012; Sharon 2013; Cuenod 2011; Weeks 2003; britishmuseum.org 2016; oichicago.edu 2016)

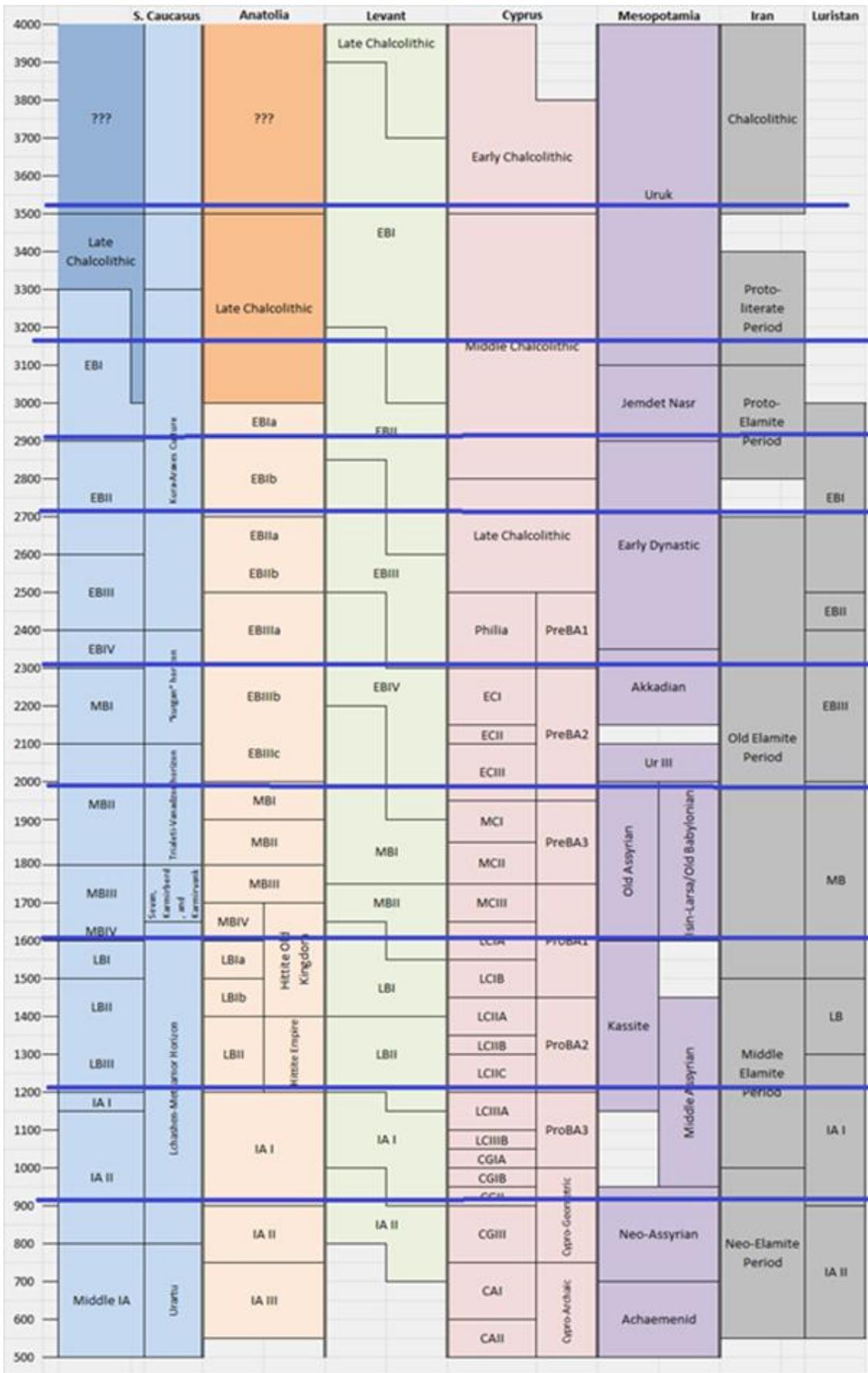


Figure 16: Chronological time scheme of Southwest Asia based on broad regional cultural change (contextual)

2.2 Chronological categorisation

With regards to categorisation of the data into time periods for this research, the millennia were split into rough thirds, though of slightly unequal size. The rationale behind the decision to use these quasi-arbitrary time periods was three-fold: they needed to be small enough in scale to enable us to explore patterns of change over time, but also large enough to maintain sensible sample sizes to justify robust interpretation and balanced to provide a buffer against chronological inexactitude in both the definition of periods themselves and the attribution of artefacts to them.

To test the robustness of the chronological divisions used in this thesis (the *arbitrary* periods, separated by rough thirds of millennia – i.e. ‘early 3rd’ = 3000 – 2651; ‘mid-3rd’ = 2650 – 2351; ‘late 3rd’ = 2350 – 2001) an alternative chronological system was employed in parallel. The alternative divisions were based on major cultural changes as far as they could be applied to the entire region of Southwest Asia by rough alignment of cultural breaks (Figure 16). The prospective breaks between the ‘*contextually dependent*’ periods are represented by a blue line across the regional timelines, and it can be seen here how they either fit or do not fit with regional chronologies of Southwest Asia. It is clear from the figure that that the Iranian, Southern Levantine and Caucasian cultural periods fitted less easily into this pan-regional chronological split: all periods of both Iranian chronologies were divided, apart from at the start of the Old Elamite and the gap between EB III and MB; all culture periods in the Southern Caucasus and some ‘Age’ definitions were also divided; and the Levantine chronology displays

too much ambiguity in start and end dates to accurately say if the broader chronological divisions were regionally appropriate or not.

In order to fully compare these two chronological divisions and ascertain which is more suitable to this research, the first thing to look at was how these different time periods divisions distribute the data into assemblages based on time and region. Table 2 and Table 3 display the number of analyses per time period and region by both the 'arbitrary' (Figure 15) and 'contextually dependent' (Figure 16) approaches. The numbers highlighted in grey are those below ten and are therefore unusable. The two approaches provide differently weighted assemblages but the result was largely negligible as regards evening out the assemblages as a whole.

Table 3: split of data as defined by *arbitrary*, evenly spaced time periods (as these tables were produced from an earlier version of the database some assemblages have since been altered: NW Anatolia = West and Central Anatolia, Assyria = Northern Mesopotamia)

	NW Anatolia	E Anatolia	Med Coast	N Caucasus	S Caucasus	S Levant	Cyprus	Assyria	Mesopotamia	Luristan	W Elam	Kerman	Caspian coast	E Arabian Pen.	Bactria	Total
Late 4th	48	51	15	0	6	9	0	2	5	3	28	3	47	0	0	217
Early 3rd	28	158	2	0	17	29	0	8	72	9	13	31	4	0	0	371
Mid 3rd	289	25	30	9	641	41	28	51	135	74	104	37	0	47	0	1511
Late 3rd	298	15	62	52	68	109	91	178	1328	36	45	45	101	262	0	2690
Early 2nd	16	2	8	2	44	99	212	34	238	60	21	1	53	67	171	1028
Mid 2nd	219	41	108	44	87	535	62	0	6	24	34	32	24	47	19	1282
Late 2nd	0	0	0	107	59	40	26	8	9	30	10	0	78	413	0	780
Early 1st	0	4	0	52	391	22	1	123	6	348	0	1	50	220	0	1218
Total	898	296	225	266	1313	884	420	404	1799	584	255	150	357	1056	190	9097

Table 4: split of data as defined by 'contextually dependent' time periods of different sizes (as these tables were produced from an earlier version of the database some assemblages have since been altered: NW Anatolia = West and Central Anatolia, Assyria = Northern Mesopotamia)

Periods	Dates	NW Anatolia	E Anatolia	Med Coast	N Caucasus	S Caucasus	S Levant	Cyprus	Assyria	Mesopotamia	Luristan	W Elam	Kerman	Caspian coast	E Arabian Pen.	Bactria	Total
P1	3500 - 3151	33	49	0	0	2	7	0	0	51	1	28	12	47	0	0	230
P2	3150 - 2901	20	32	15	0	6	2	0	4	23	8	0	14	0	0	0	124
P3	2900 - 2701	28	123	3	0	16	51	23	6	49	3	13	17	6	1	0	339
P4	2700 - 2301	297	25	30	9	642	44	28	107	653	79	110	35	95	89	0	2243
P5	2300 - 2001	290	15	62	93	71	110	91	122	813	31	40	44	6	220	0	2008
P6	2000 - 1601	16	2	13	6	44	288	214	34	241	62	21	33	53	49	190	1266
P7	1600 - 1201	219	41	102	141	133	393	76	10	7	28	44	3	65	81	0	1343
P8	1200 - 901	0	0	0	9	335	6	10	8	12	85	0	0	71	40	0	576
Total		903	287	225	258	1249	901	442	291	1849	297	256	158	343	480	190	8129

The crucial issue was to ascertain to what extent the chronological distribution of data affected the results; does attribution of data to different time periods affect the pattern visible in the resulting copper assemblage? In order to test the legitimacy of both of these approaches the percentage of the Mesopotamian copper-base assemblage made of copper group 1 (no traces of arsenic, antimony, silver or nickel – described in section 4 of this chapter) was plotted by both chronological methods (Figure 17 and Figure 18).

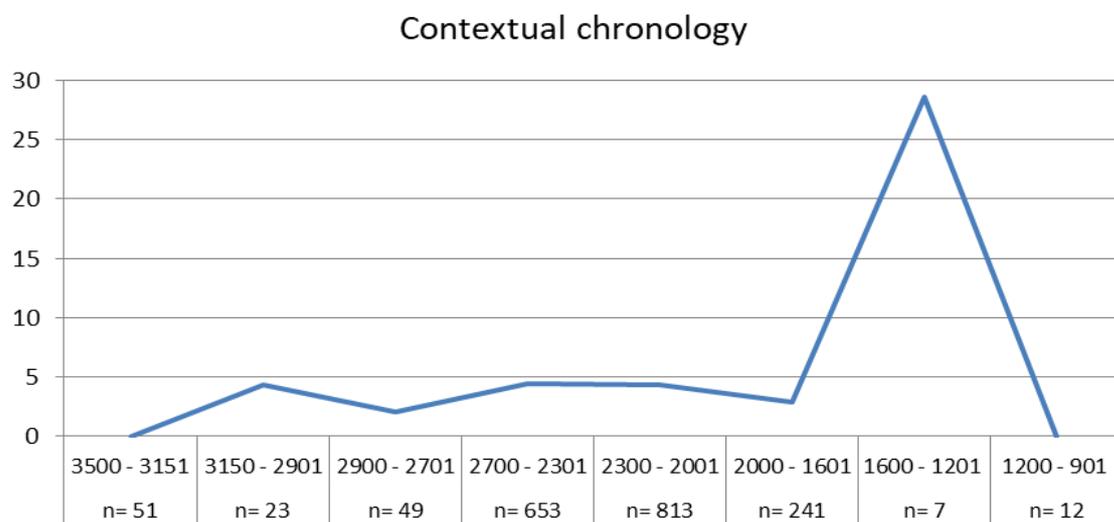


Figure 17: Percent of entire Mesopotamian copper-base assemblage made of copper group 1 (containing no traces of arsenic, antimony, silver or copper) split into a *contextually dependent* chronology

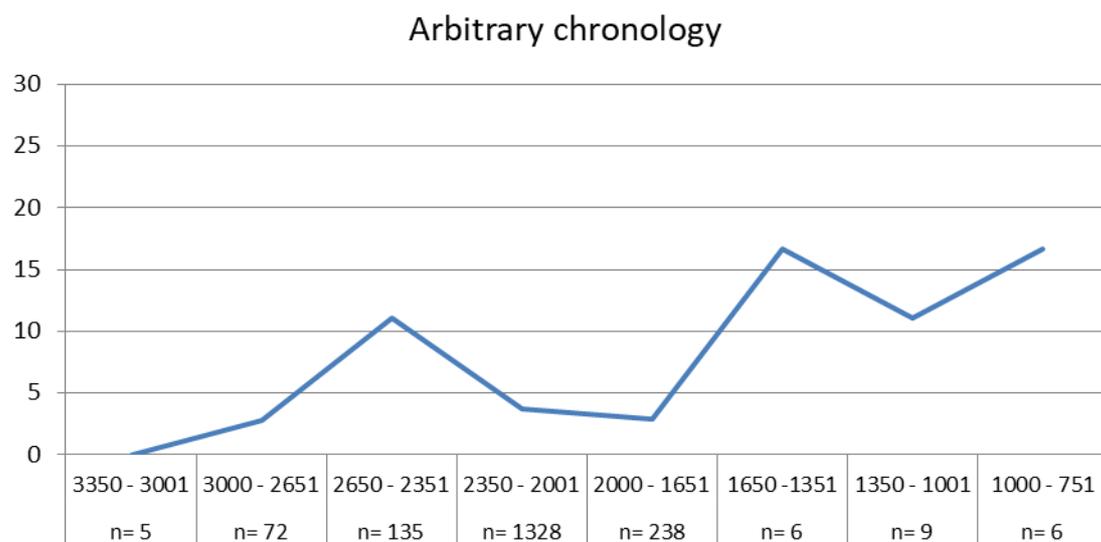


Figure 18: Percent of entire Mesopotamian copper-base assemblage made of copper group 1 (containing no traces of arsenic, antimony, silver or copper) split into an *arbitrarily defined* chronology

The advantage of the *contextual* chronology was only useful in that it separated out the data for the Early Bronze Age (Figure 17), providing a more nuanced picture where there was the data to support it. However it also condensed the second millennium into only two periods, which did provide larger assemblages, but they became less nuanced in the process and some patterns of change were lost when condensed (for comparison see Figure 18).

The variation in period length also posed a problem – a period of two hundred years at the beginning of the third millennium was given as much visible significance as almost half of the second millennium, a scheme which does not provide an even field for noticing patterns and emphasizes those regions in which the 3rd millennium BCE has been more thoroughly investigated.

In addition, although the *contextually dependent* categories were based on general moments of cultural or socio-political change across Southwest Asia, they could never accurately represent trends of change equally in all regions: this would effectively prioritise those regions which have been studied in tandem with one another throughout archaeological history. They could also not be applied to any other additional regions outside of Southwest Asia. This is especially important to bear in mind along with the knowledge that for much of the past two centuries ‘Near Eastern Studies’ have been overwhelmingly Meso-centric, and the chronologies reflect that bias: ‘peripheral regions’ were frequently contextualized through their perceived centre, which was more securely dated owing to the larger focus of regional study. The aim of this research is to make comparisons across a large area, which cannot be done objectively if the chronologies of a handful of regions are prioritised over others. What is interesting is that in both chronological

examples the change in pattern of copper use over time remains generally similar with both chronologies, suggesting that these patterns themselves are reliable.

To summarise, the initial '*arbitrary* chronology' was used, rather than the '*contextually dependent* chronology' in order to provide a series of snapshots over time through which to view change in patterns, while simultaneously allowing for varying archaeological traditions in recording of data and artefacts. This is also an attempt to present a general view of the movement of copper and its alloys over time and space: it is therefore impractical to attempt to base the assemblages on a chronological scheme that does not fit all regions of interest. Where there is something to focus on within a specific region it is then possible to look at that data with the correct and regionally specific chronology applied.

2.3 *Category assignment*

If the time range given for an analysed object is larger than one of the '*arbitrary chronology*' periods or crosses the boundary of one or more periods, it has been assigned to the period in which the mid-point falls. For example, the mid-point an object dating from 3000 to 2200 BCE is 2600BCE, and it therefore is categorised as mid-3rd Millennium BCE (2650 – 2350 BCE). The reasoning behind this is that the mid-point will fall within the period during which most of its potential existence has been and is therefore more likely to belong to that period. This approach has been used on time periods of up to 1100 years, but any object with a larger time period attributed to it has been left out of the analysis.

A large number of objects from the Caucasus are only described as “3rd Millennium” in the literature: these have all been categorised as “*mid-3rd millennium*” in the database. Clearly this is less than ideal. One possible alternative to this dilemma would have been to attribute objects to all time periods covered (effectively tripling their quantity in the database), however this would place more importance on objects analysed by certain technical methods and enhance the differences between analytical techniques. In Cuénod (2013), objects covering such large time frames were assigned to the earliest time period, however that approach is not suitable here as much of this research focusses on when alloys were first adopted. If there were more usable data in the archaeological record, such ambiguous dating techniques could be avoided, and those analytical results cut from the database.

A second option would be to randomly assign 3rd millennium objects to each of the three periods, therefore distributing the chances of biasing the data, however if all the objects with vague time frames are kept within one period, more reliability can be placed on the data from the periods on either side. As it is, caution must be reserved for outlandish results relating to the mid-3rd millennium and mid-2nd millennium BCE in certain regions.

2.4 *Chronological obscurity in legacy data*

As is the case when categorising keys and differing schemes which have been inherited by numerous sets of researchers, the time-codes within the SAM database (Krause 2003) were difficult to interpret. A large part of this stemmed from the original European focus of the research, which was then adapted to incorporate a wider region, and additional time schemes tacked on during collection.

A workable chronology has been arrived at but its reliability will always remain somewhat uncertain. The presence of duplicate data (see section 1.3 in this chapter) was not sufficient to aid interpretation as there were discrepancies between the two sets (i.e. objects dating to the time-period “Gaura 4; Ur III; BzA1” in Krause (2003), variously fall into the periods “Karum I”, “karum II”, “Copper Age” and “Hittite” in Esin (1969)) This constituted a dilemma of choice: to use the data provided with an unreliable chronology, or the data connected to an older chronology which could be out of date. As mentioned earlier, the SAM data was chosen in order to keep data compatibility within the database.

As mentioned above, the chronological key that accompanied the digitized SAM database (Krause 2003) was focussed toward Central European prehistory. Several different chronological periods were assigned to each numerical code, or were provided with actual dates, which in turn were attributed to an object. Chronologically these time periods varied significantly, even up to a millennium. For ease of description each time code has been allocated a colour (Figure 20) and each chronological type-site period depicted on a timeline (Figure 19).

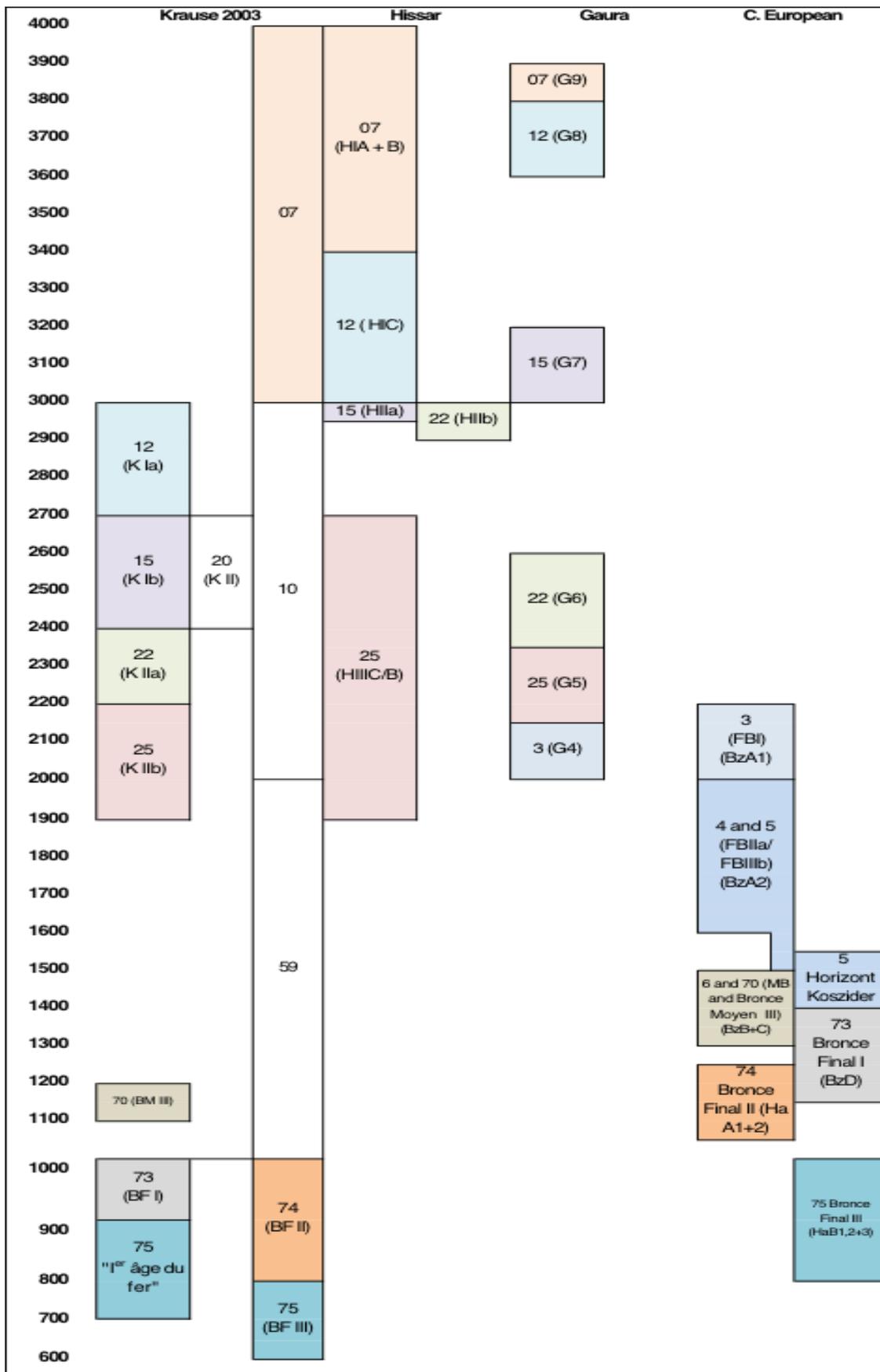


Figure 19: Dates of each time code by separate chronology listed to highlight disparity between the dates they refer to by chronological schemes

07	4. Jahrtausend; Hissar IA und B; Gaura 9
10	3. Jahrtausend; K I
12	3000–2700; K Ia; Hissar IC; Gaura 8
15	2700–2450; K Ib; Hissar IIa; Gaura 7; Karan. VI
20	2700–2450; K II
22	2450–2200; K IIa; Hissar II, IIb; Gaura 6
25	2200–1900; K IIb; Globe SK; Schw. Pfahl; Hissar III C/ B; Gaura 5
3	FB I; Gaura 4
4	FB IIa
5	FB IIb; Horizont Koszider
59	2. Jahrtausend
6	Mittelbronzezeit
70	bronze moyen III; Briard 1200–1100
73	bronze final I; Briard 100–900
74	bronze final II; Briard 1000–800
75	bronze final III; Briard 800–600; „Ier âge du fer“ 900–700

Figure 20: colour coded key of time periods for the chronological chart, with descriptions as published (Krause 2003)

Codes 07 to 25 provided the most challenging problem as dates were given, but they did not correspond to the type-site periods also referenced. An example is that of code 12: “3000 – 2700; K Ia; Hissar IC; Gaura 8” (Krause 2003). All possible dates provided in this time code span over a millennium and a half. A fair assumption is that the dates and periods provided refer to specific regions, i.e. Tepe Hissar would apply to all objects from Iran assigned to code 12, and the same for Tepe Gaura and Iraq. However, code 12 was assigned to objects from the Caucasus, the Levant, Cyprus and Turkey, as well as Iran and Iraq. For the 3rd millennium BCE the Tepe Gaura chronology was chosen as it seemed to have more application to regions such as Anatolia and the Levant: in the past these regions have been viewed as peripheries and therefore the chronological periods might bear more correspondence with the Gaura chronology. Tepe Gaura is not a reliable type-site as it is securely dated mainly relative to itself and is only firmly dated up to Gaura 7 (for these dates refer to Rothman 2002). Gaura 6, 5 and 4 had to be

dated by the links to Mesopotamian time periods in the literature (Early Dynastic III, Akkadian and Ur III respectively).

The time periods of the second millennium were interpreted as Central European descriptions, and the dates followed accordingly. One of the principal chronological systems used in Central Europe is that established by Reinecke for Bavaria and later incorporated into the wider region (Harding 2000, p.10). Though the Late Bronze Age codes made use of the French chronological system, these were also related to Reinecke's chronology as used by Roberts *et al.* (2013, p.19). The final chronology chosen and used for the data provided in the SAM database is shown in Figure 21.

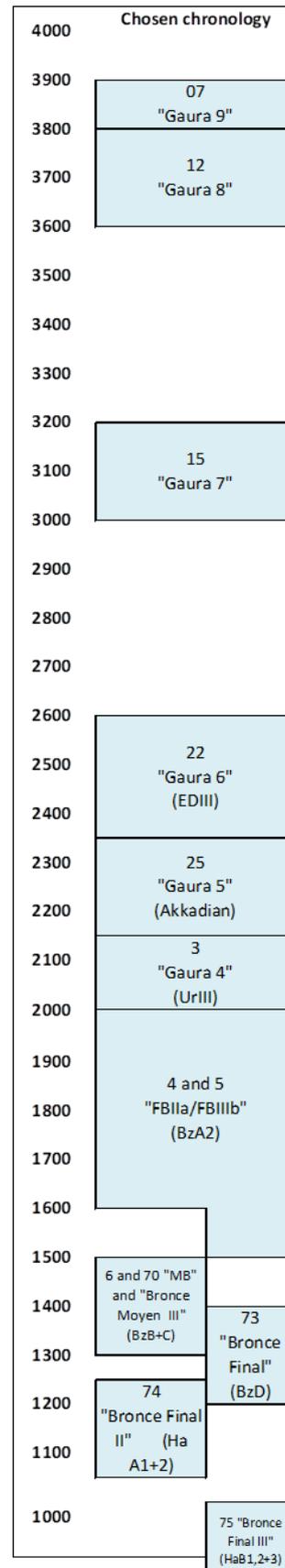


Figure 21: chronological categories used in database

3 Geographical scope

This research aims to provide a chronological time frame for the patterns of technological change across Southwest Asia. Though the regions represented in this thesis had contact and exchange extending far beyond Southwest Asia, it is these regions that are interconnected time and time again over several millennia. Cultural expansion, transmission of goods and ideas and the changing nature of politics are highly connected across the sub-continent, with varying levels of intensity. The distribution of sites included in this thesis (excluding sites for which no co-ordinates could be found) is displayed in Figure 22.



Figure 22: Map depicting the sites included in the database of Southwest Asian copper-base objects used in this thesis for which co-ordinates could be found

3.1 Regions

Though modern political boundaries have no bearing on those of the past, regions have to be formed to make categorisation of data easier to digest. The regions were chosen partly on the foundation of previous regional research, which is admittedly usually focussed within one modern country. The regions are not wholly culturally specific, as during the long timeframe covered in this research regional dominance expanded, receded and was often fought over. The zones have therefore also been separated or combined owing to topographic features. For example the Mediterranean region of Anatolia and the Northern Levant are presented as one region (the “Mediterranean Coast”) owing to their coastal nature and the influence this had on maritime trade. Where cultures have expanded or receded at certain times in history, they are mentioned in the discussion, but the physical regions discussed have fixed boundaries for the purposes of this thesis. Figure 23 is a map of the regional zones.

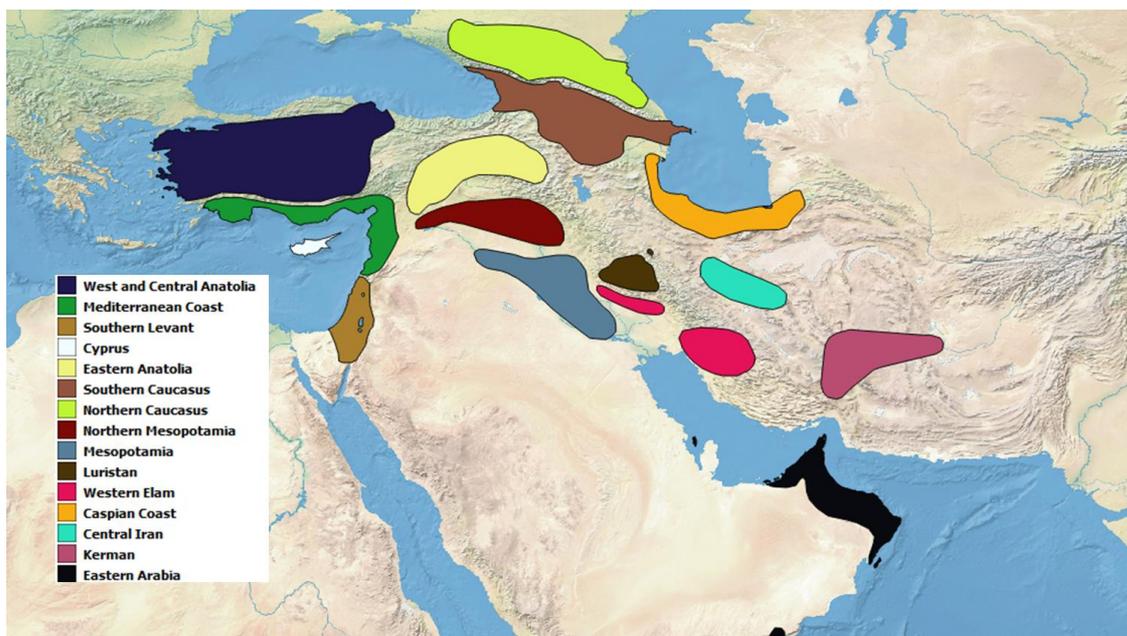


Figure 23: map of Southwest Asia depicting regional areas used in this thesis

4 The 'Oxford System'

The main aim of the Oxford System is to create a toolkit which allows for the detection of change and continuity in patterns of metal use over time and space. By developing a set of diagnostic tools that can be applied indiscriminately to data that crosses national and linguistic barriers, the flow of copper across vast swathes of the globe can be systematically studied. Within this system copper objects and fragments are considered base units of the wider flow of material in use and by studying the assemblages chronologically and regionally, patterns of change and continuity can be ascertained. These patterns can then be studied more closely in a way that may provide information about human interaction and activity.

However inherent bias in the database must be remembered as certain object types may have been analysed more frequently. This poses a problem if there were systematic differences in copper composition used for different objects, for example the daggers and axes found in the Moons Hill Hoard on the Isle of White (Needham *et al.* 1989).

Historically, archaeometallurgical studies, especially in Southwest Asia, have focussed on the provenance of metals in use in the region. By linking the chemical 'fingerprint' of objects to those of ore sources, it is hoped to establish evidence of trade and communication between regions. Certain assumptions have to be made before this can be successful: that the trace elements in the ore automatically and with an unchanged ratio transfer to the resultant metal during smelting; that the object follows a direct and linear trajectory from ore to raw material, from raw

material to object, to trade of object and deposition of the unchanged object in the same region; and that no recycling, re-melting, mixing or fixing of the object occurred during its linear lifespan. There may be many objects which did follow such a trajectory, but it cannot be assumed for all objects.

Recycling in this sense is not intended to carry connotations of modern, waste-reducing recycling, but to convey the myriad changes that may have been applied to the metal in question: an edge of a knife blade that is reheated and retouched; a single object melted down and recast as another single object; several items recast into one large item; or a combination of objects, scrap metal and fresh metal melted down and mixed to create a new batch of raw material. All of these processes affect the chemical composition of the metal in use – the ‘fingerprint’ elements could become mixed, diluted, or the more volatile chemicals lost. Even if the object remains in its original, first-cast shape there is no telling how long it was in circulation, or how many times it has been traded, gifted, lost or moved.

There are three main approaches to the Oxford System(Pollard *et al.* 2018):

“The Toolkit: the ‘Oxford system’

Based on the model developed above, we have devised a system (sometimes referred to as ‘the Oxford system’), which is based on a set of three separate but interlinked groups of tools:

trace element composition or ‘Copper Groups’, which focusses on information derived primarily from the copper ore source(s), but which may potentially be altered by subsequent human manipulation of the metal,

alloy composition (‘Alloy type’), which is defined to be the result of intentional action, as craftspeople choose to add metals to modify the characteristics of the material (fluidity in casting, colour, hardness, etc., or perhaps to give additional symbolic significance),

but subsequent mixing and recycling might move the assemblage away from the originally-designed alloy compositions,

lead isotope composition, which can give information about the source of copper, or the added lead, but is also susceptible to alteration due to anthropogenic mixing.”

Only the first two ‘tools’ are considered for this thesis as lead isotopic composition was not routinely analysed across the copper assemblages of Southwest Asia.

4.1 Trace element composition: Copper Groups

The Oxford System for trace elements revolves around the allocation of copper finds into ‘copper groups’ in order to tease out geographical and chronological patterns of change in the use of metals, first used by Bray (2009) to study copper

	As	Sb	Ag	Ni
Clean				
As	■			
Sb		■		
Ag			■	
Ni				■
AsSb	■	■		
SbAg		■	■	
AgNi			■	■
AsAg	■		■	
SbNi		■		■
AsNi	■			■
AsSbAg	■	■	■	
SbAgNi		■	■	■
AsSbNi	■	■		■
AsAgNi	■		■	■
AsSbAgNi	■	■	■	■

Figure 24: group composition categories. Coloured square indicates presence of element (>0.1%)

use in Britain and Ireland, and consequently by Bray and Pollard (2012), Cuénod (2013), Perucchetti (2015), Hsu (2016) and Liu (2016) and now as part of the FLAME project, across many parts of Eurasia.

The first step of this method is to define each object, scrap or fragment in the database by copper group. Copper is assigned to the different groups by the presence or absence of arsenic (As), antimony (Sb), silver (Ag), and nickel (Ni). Figure 24 shows the combination of each group – a coloured square denotes the presence of the element labelled at the top of the column and a blank

square its absence. These elements represent a range of thermodynamic

behaviour, from arsenic (the most volatile) to nickel (the least volatile). As these elements react differently to being reheated or melted, their change can be reflected in the copper groups.

When discussing the copper groups, the use of the word 'clean' refers only to these four elements, and is not meant to imply copper "free from impurities" – copper from copper group 1 ('clean') could contain cobalt, bismuth, and lead, etc. It is also necessary to clarify that these groups are not considered as specific sources or as 'types' of metal known and used by ancient metallurgists. They are not static groups and copper can move between them, something which allows us to study the patterns they create in the archaeological record.

For example, copper smelted from an arsenic bearing ore and buried in the form it was cast would likely be attributed to copper group 2 (As-only). If the object contained alloying levels of arsenic (>1%) it would still be considered within this copper group for the purposes of the flow of copper. In studying the broad distribution of copper group 2 (As-only) through space and time it might be possible to identify patterns of production and distribution. This kind of general approach was used to great effect by Chernykh (1966; 1970) in his studies of the early metal age of the former Soviet Union. Within such a system, we might even expect traditional provenance studies to be possible. However, we have to recognise that such a direct pathway from ore to object will be taken by a relatively small proportion of the metal produced within a given society. Most metal objects will go through phases of finishing, polishing, reworking, reshaping, and so forth, during their lifespan. This is a reductive process and, given the issues

associated with arsenic segregation, a proportion of the arsenic within an object may be lost.

Such objects may eventually be re-melted (with a possible further reduction of arsenic in the process). While there is a stable supply of new 'high' arsenic metal within the system, such losses may be imperceptible, but if the supply of this metal ceases we would expect to see a gradual drop in the levels of arsenic present in the metal objects produced, used and deposited. Eventually, significant parts of the assemblage would contain sufficiently low levels of arsenic that they would fall below our thresholds for this element (see below), these would then be classified as 'clean' copper group 1 metal. We would expect similar patterns where exchange away from a production region saw metal moving across both physical and cultural space. As different societies chose to rework the metal they received into their own preferred forms or types, the processes of transformation could result in chemical change. This could happen slowly, through simple recycling of a single circulating stock, or it could happen more abruptly as a result of mixing one kind of metal with another. In both cases we would see structured patterns of change across space and/or time in the general character of the copper in circulation.

This consequence is clearly not something tangible that we see in the database, as the objects are analysed in their final form and we cannot guess whether or not they were originally made out of arsenical copper. However, if we accept that recycling and re-use of copper occurred (or at least if we accept that the *possibility* that recycling occurred) throughout the Bronze Age then the stream of copper in use will have been transformed by human activity. Even if the chemical 'fingerprint' matched that of an ore source, could it be said with certainty that it

was not an altered 'fingerprint'. However by taking a snap shot of copper in use at certain intervals and its overall composition within that assemblage and comparing this to assemblages of other periods or regions, we can begin to see a pattern of use as each group oscillates. This pattern is then studied alongside the archaeological context.

Though this method only uses As, Sb, Ag and Ni for interpretation, this is not to suggest that other elements such as bismuth, cobalt, sulphur etc. are not equally useful. The four elements chosen cover a range of thermodynamic behaviours in oxidizing and molten conditions, resulting in a diagnostic pattern shift if treated consistently. These elements are also often linked to various ores within this region; for example arsenic and nickel with Omani copper (Begemann *et al.* 2010) and have therefore been sought often by archaeometallurgists. Bismuth and cobalt have also been commonly sought over time, though not as consistently, but adding a fifth element would widen the number of categories of to an unwieldy 32 copper groups.

4.2 *Presence/absence threshold*

The baseline for the assignment of copper to one of the sixteen copper groups depends on the 'presence' or 'absence' of each of the elements in question (As, Sb, Ag, Ni). The minimum threshold for an element to be considered 'present' in the Oxford System is 0.1%. Though in some respects this cut-off value is arbitrary, it provides universality across and large and varying dataset. The numerous analytical techniques used in the acquisition of data across Eurasia has resulted in

many differing minimum detection levels, both between elements and between research programmes. Modern techniques may have minimum detection levels of 0.01% or lower, but optical emission spectroscopy (with which the main bulk of copper from the Caucasus was analysed) may have minimum detection levels as high as 0.1% (Pollard *et al.* 2018). In order to utilize all data from across Eurasia equally the threshold for ‘presence’ or ‘absence’ must be higher than the minimum detection level for all techniques. This allows for pan-regional synthesis of data.

In Bray’s original (2009) study and Cuénod (2013), the minimum threshold of presence varied for each element: As 0.25%, Ni 0.1%, both Ag and Sb 0.05%. These cut off values were chosen in relation to the behaviour of the elements themselves as displayed in distribution diagrams (Cuénod 2013, p.270). This added a subjective and regional influence on the resultant pattern and was therefore not as easily compared with assemblages from a wider geographical territory. It also ran the risk of silver and antimony being obscured from older analytical programmes.

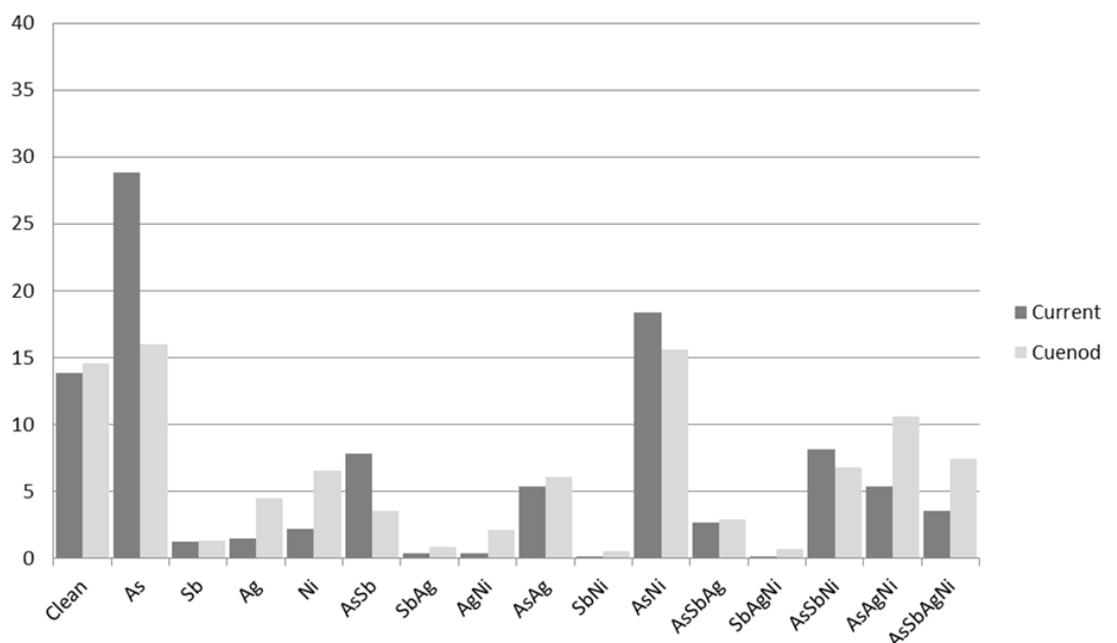


Figure 25: Difference produced by changing the minimum threshold level of each group applied to the entire copper-base assemblage from Southwest Asia. Cuenod: As 0.25%, Ni 0.1%, both Ag and Sb 0.05%, Current: 0.1% As, Sb, Ag, and Ni

Figure 25 depicts the entire Southwest Asian copper-base assemblage assigned to copper groups based on the former presence threshold and the current, to compare the differences in copper group pattern dependent on approach. The main difference between the two approaches is the larger percentage of the total assemblage assigned to copper group 2 (As-only) using the current methodology. There are also fewer objects assigned to copper groups 15 (AsAgNi) and 16 (AsSbAgNi).

4.3 Normalisation of data

The analytical data contained in this database was not normalised to 100% of the object weight, the reason being that the aim is to understand the reasons behind patterns of change, and this is more accurately achieved if the *actual* compositional quantity of alloying elements measured is used for analysis, rather than the *theoretical* compositional quantity. Objects with low totals when all element quantities were combined were removed from the study. Another reason why all the data was not normalised is the variable nature of much of the data itself: often there was no numerical quantity for copper, usually when the analytical method was Emission Spectroscopy. In some instances it was labelled 'bulk' or 'main' and in others it was not provided. Although less than ideal, in these cases the cumulative quantity of all other elements provided was detracted from 100%. This is problematic for several reasons, the main being that it is highly unlikely any analytical results will neatly amount to 100%, and it presumes that all elemental composition sought was provided. However this approach was the only option available without sacrificing an enormous amount of data. It also meant

that normalising the data that did have copper totals provided might enhance quantities of trace elements and distort the findings of certain assemblages. As this often relied on the analytical method used in its procurement and, as discussed more fully in section 1.2, the choice of method was often regionally or temporally biased it would render inter-regional or inter-chronological comparison unsound.

In the case of designating copper groups, the four elements (As, Sb, Ag, and Ni) must be normalised to the object total after the removal of *purposefully added* components. The totals of zinc, lead, and tin were detracted from the (un-normalised) total, and the remaining ‘impurities’ were normalised. This clearly represents an issue over the question of deliberate alloying of arsenic, which is especially pertinent to this research, and indeed antimony, silver, and nickel as well. However in the diagnostic stage of copper group categorization intentionality behind the resulting composition is not in focus: it is the question of copper in circulation at that time and its patterns of change that is under scrutiny. Further assessment of alloying traditions which *do* include arsenic, antimony, silver, and nickel are dealt with separately. The main aim in the process of categorizing copper groups is to ensure that copper containing above the presence threshold of a diagnostic element *before* tin, zinc, or lead was added does not become obscured by the saturating effect of the added material.

4.4 *Copper Group Ubiquity*

Once all data in the database is assigned to its Copper Group, the next step is to calculate the ubiquity of each group within an assemblage. The term ‘assemblage’

here does not imply a fixed entity as it can be defined by the research question being asked of it. ‘Assemblage’ in this thesis generally refers to the objects from a specific region rather than a site, and from a specific time period (as outlined in section 2.2). For example, if comparing copper objects from across Anatolia throughout the 3rd and 2nd millennia, the collection of *early 3rd millennium* copper-base objects from *Eastern Anatolia* would count as one of the assemblages under scrutiny. This ‘assemblage’ can then be broken down further: the *tin-bronze* (>1% Sn) assemblage from *early 3rd millennium Eastern Anatolia* can be compared against the *unalloyed copper* assemblage from *early 3rd millennium Eastern Anatolia*. The ubiquity of each copper group is presented as the percentage of objects of in each copper group based on the total of that assemblage.

Region (e.g. E Anatolia) → Copper Groups

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Assemblage total
	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi	
Time ↓	Late 4th	Percentage of assemblage (number of objects in each group/total of all objects made of each copper group*100)															
	Early 3rd																
	Mid 3rd																
	Late 3rd																
	Early 2nd																
	Mid 2nd																
	Late 2nd																
	Early 1st																

Time (e.g. Mid-3rd millennium) → Copper Groups

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Assemblage total
	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi	
Region ↓	W&C Anatolia	Percentage of assemblage (number of objects in each group/total of all objects made of each copper group*100)															
	E Anatolia																
	N Mesopotamia																
	Mesopotamia																
	W Elam																
	Luristan																
	S Caucasus																
	E Arabia																

Figure 26: Example tables of how copper group ubiquity tables are presented throughout this thesis. Upper table depicts one region through time, the lower a table across space during one time period

This is then typically presented in the form of tables which display all chronologically assigned assemblages in one region or regionally assigned assemblages during one time period. Figure 26 is an example of these tables. It is

then possible to infer patterns of change across space and time by the oscillation of certain groups. If the assemblage contains fewer objects than twenty then this is highlighted by hatched lines owing to the distortion this may place on the results.

There are further steps that can be taken such as element profiling and certain mapping techniques of the assemblages, however these are not included in this research so will not be outlined. For a full description of further possible applications of the Oxford System for trace elements see Pollard *et al.* (2018).

4.5 *The Oxford System for alloying composition*

The approach to ancient alloying is similar to that of the Copper Group allocation, as it involves classification of alloys based on ‘presence’ or ‘absence’ of alloying elements (tin, lead, zinc, arsenic, antimony, silver, and nickel). Although iron is not a traditional alloying element owing to the detrimental affect it has on copper (discussed in more detail in Chapter Five, section 8.1), it is also included as it indicates certain practices and changes in metallurgical tradition.

The threshold for an element to be considered an ‘alloying element’ is a minimum of 1% for each of these elements. This value is lower than those used for perceptive levels of alloying elements (Lechtman 1996; Kuijpers 2017; Mödlinger *et al.* 2017), however it is considered for several reasons. Firstly, unintentional alloying though not relevant to active human interaction with material nevertheless highlights certain aspects of ore choice and copper in use across Southwest Asia. Secondly, though the fabrication of an alloy may have been intentional, in some instances there may have been less control over the final

composition of the material. Thirdly, recycling and/or mixing of copper alloys may result in dilution of the alloying signal. By lowering the alloying presence threshold to 1%, non-standard alloys are not obscured from the record (Pollard *et al.* 2018).

In Chapter Five the aim is to ascertain changing alloying patterns across space and time and to investigate them alongside the archaeological context. In Chapter Seven alloying traditions based around *perceptive categories* are considered to answer questions about intentionality and human interaction with, or awareness of, the material (Mödlinger *et al.* 2017; Kuijpers 2017). The methodology behind this is described in Chapter Seven, section 3.

In Chapter Five section 8.1 the level of focus is slightly different and therefore the presence threshold has been altered: the aim is to study pre-3rd millennium BCE tin-bronzes, some of which may have been produced accidentally. As copper-tin ore is not abundant in this region, the criterion for copper to be considered as a copper-tin alloy has been widened: the presence threshold here is considered at 0.5% Sn. It is not suggested that these alloys were necessarily recognisable, but this cut-off value allows for isolated pockets of early tin-bronze use to be visible in the record, and from there scrutinized further.

5 Chapter Summary

In this chapter many advantages and disadvantages to the collation of a large data set spanning several regions, millennia and centuries of archaeological research have been discussed. The reasoning behind solutions to several obstacles towards the legitimacy and compatibility of the data have been outlined. The chief drawbacks of such a database are ambiguities in contextual and analytical notation, the unevenness of regional research interest, and a variation in analytical techniques, all of which are to be expected over the course of two centuries worth of archaeometallurgical research and development of a discipline. A similar issue is the integration of several chronologies developed by different archaeological traditions, conducted in various languages on regions that have culturally overlapped for millennia.

The advantages of a large dataset include placing less reliance on individual objects or a small set of objects, in which the analytical technique used may have more of an influence, and via which implicit assumptions are made regarding comparisons of such small sets. In considering broad patterns of change, the larger the dataset the more diagnostic the initial analytical steps. It is then important to look more closely at the resulting patterns alongside the archaeological context, so as to avoid reduction of people and objects to compositional categories.

Chapter Four: Regional Profiles

In this chapter each region will be characterised by a metallurgical profile, the aim of which is to create a consistent summary of regional practice that can be compared across space and time. These profiles include patterns of copper and copper-alloy use; the tin content of all tin-bronzes in each assemblage; the diversity of copper groups and their fluctuation between dominance, presence and absence; and finally the average arsenic, antimony, silver and nickel contents of assemblages. Each region will be addressed in an order roughly in keeping with a northwest to southeast orientation, in so far as possible, starting with West and Central Anatolia and ending with Eastern Arabia. As the region covered in this thesis is so vast, certain topics of discussion are presented in the text as they will not be returned to in the discussion chapters.

Table 5: Breakdown of number of objects within copper-base assemblages by period and region

	W and C Anatolia	Med Coast	Cyprus	S Levant	E Anatolia	S Cauc	N Cauc	N Mesop	Mesop	W Elam	Luwistan	Caspian Coast	E Arabian Peninsula	Keaman	Total
Late 5th	2	0	0	0	0	25	0	3	0	0	0	5	0	2	37
Early 4th	20	21	6	86	4	17	0	4	0	68	0	33	0	2	279
Mid 4th	10	0	0	0	1	6	0	24	66	0	1	7	0	17	135
Late 4th	44	15	0	9	39	40	92	18	5	28	3	47	0	3	375
Early 3rd	74	2	0	29	162	18	0	8	72	13	9	4	0	32	423
Mid 3rd	289	56	31	40	21	634	180	65	101	123	55	0	47	37	1680
Late 3rd	299	70	93	106	10	85	25	190	1316	44	36	101	262	63	2701
Early 2nd	16	87	214	31	2	60	14	59	213	19	60	53	67	1	1079
Mid 2nd	209	118	62	503	49	84	51	10	6	35	23	24	47	32	1272
Late 2nd	0	0	26	43	0	61	106	12	5	20	31	78	35	0	417
Early 1st	0	0	1	22	22	391	52	123	6	0	349	51	220	1	1241
Mid 1st	0	0	0	4	0	29	1	4	41	1	17	17	0	3	118
Late 1st	13	0	0	0	0	18	0	8	2	0	1	0	0	12	54
Total	988	369	433	873	311	1472	521	529	1834	351	585	420	678	211	9838

Table 5 is included here for reference of total numbers of objects in each assemblage, though where the assemblage is small enough to be unreliable the number is indicated in the relevant chart.

1 West and Central Anatolia

1.1 *Bronze ubiquity*

From the late 4th millennium to the mid-2nd millennium BCE, arsenical-bronze was generally the dominant copper alloy in West and Central Anatolia (Figure 27). Tin-bronze use in the region reached its peak in the mid and late 3rd millennium, just equalling the use of arsenical-bronze at between 30% and 35% of the assemblage. Tin-bronze use then decreases in the 2nd millennium, accounting for only 12% of the assemblage.

The use of tin-arsenic-bronze (>1% As and Sn) increases steadily from the beginning of the 3rd millennium to the mid-2nd millennium BCE (Figure 28). This could indicate mixing of arsenical-bronze with tin-bronze over time, or the addition of tin to local, arsenic rich copper sources. Unalloyed copper increases from the mid-3rd millennium to the mid-2nd millennium at a similar rate to mixed-bronze – both situations together could indicate increased reuse and recycling of objects, as on the one hand we see a potential loss of arsenic and on the other an addition of an alloying-component to an already alloyed material.

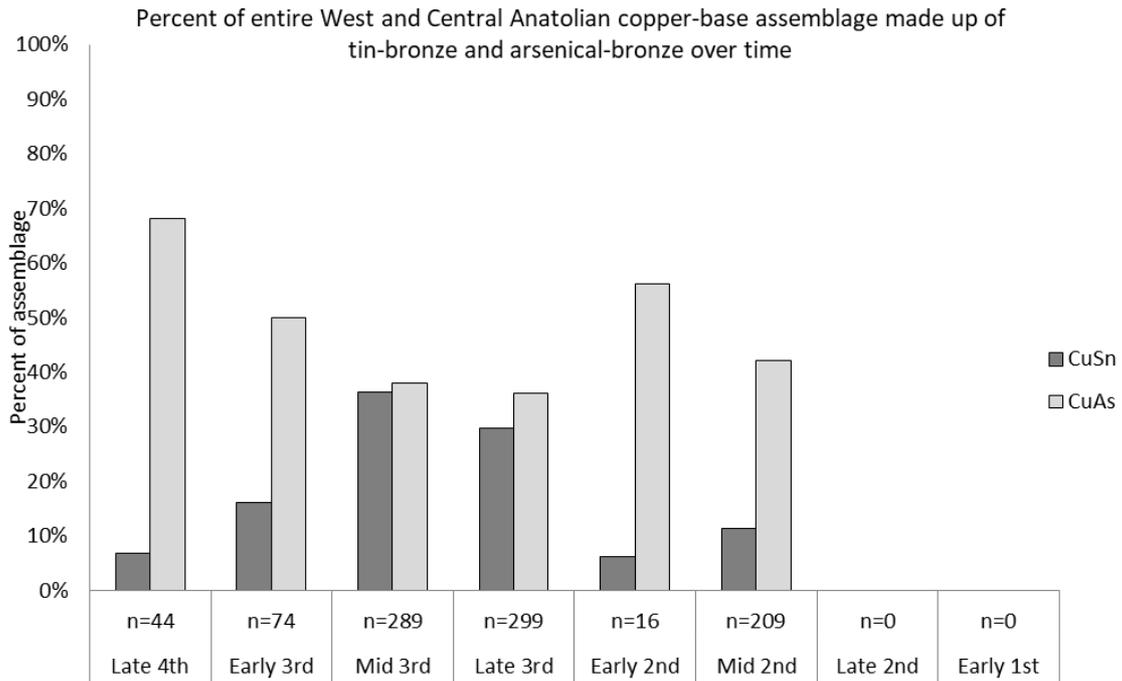


Figure 27: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in West and Central Anatolia.

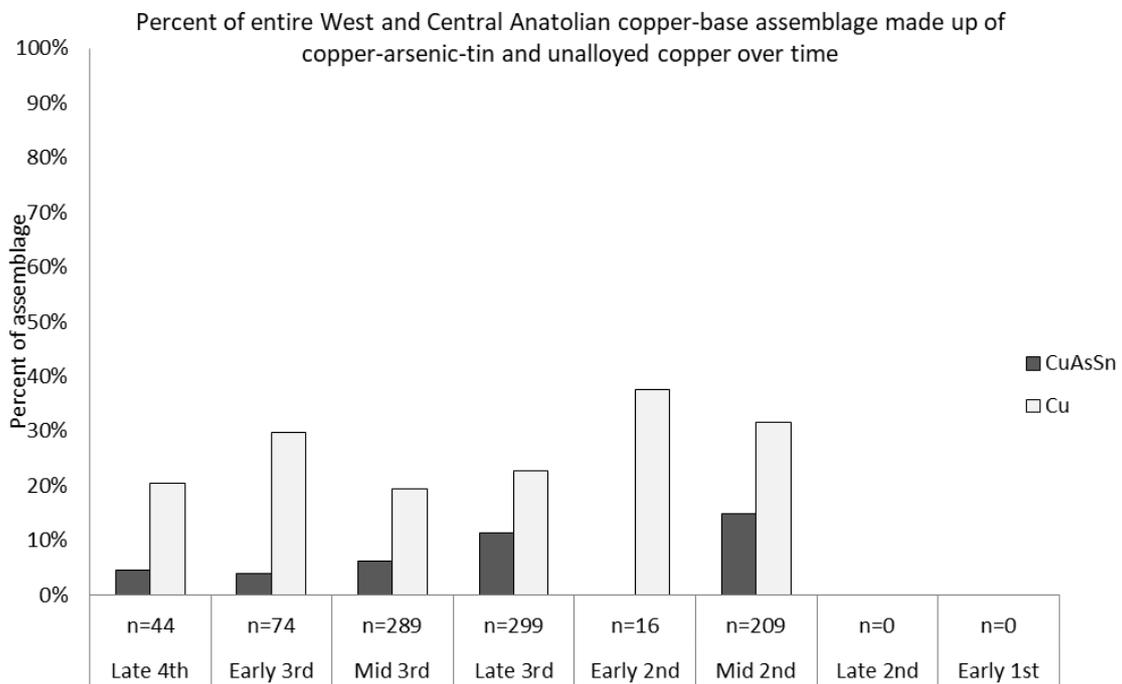


Figure 28: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in West and Central Anatolia.

1.2 Tin content

The tin-bronzes from the late 4th millennium BCE represent a small and similar group of material with medium to low tin concentrations (Figure 29). However once we move into the early 3rd millennium BCE this pattern alters completely; not only does the median tin content jump to ~12% but there are also two unusually high tin objects (a dagger containing 30% and a pin containing 35% Sn). The large range of tin composition at this time period between 6% and 35% Sn reflects little uniformity. In the mid-3rd millennium and late 3rd millennium BCE the median stabilises around 8-9% Sn, and larger numbers of objects fit into smaller ranges seeming to show a level of stability in metallurgical tradition.

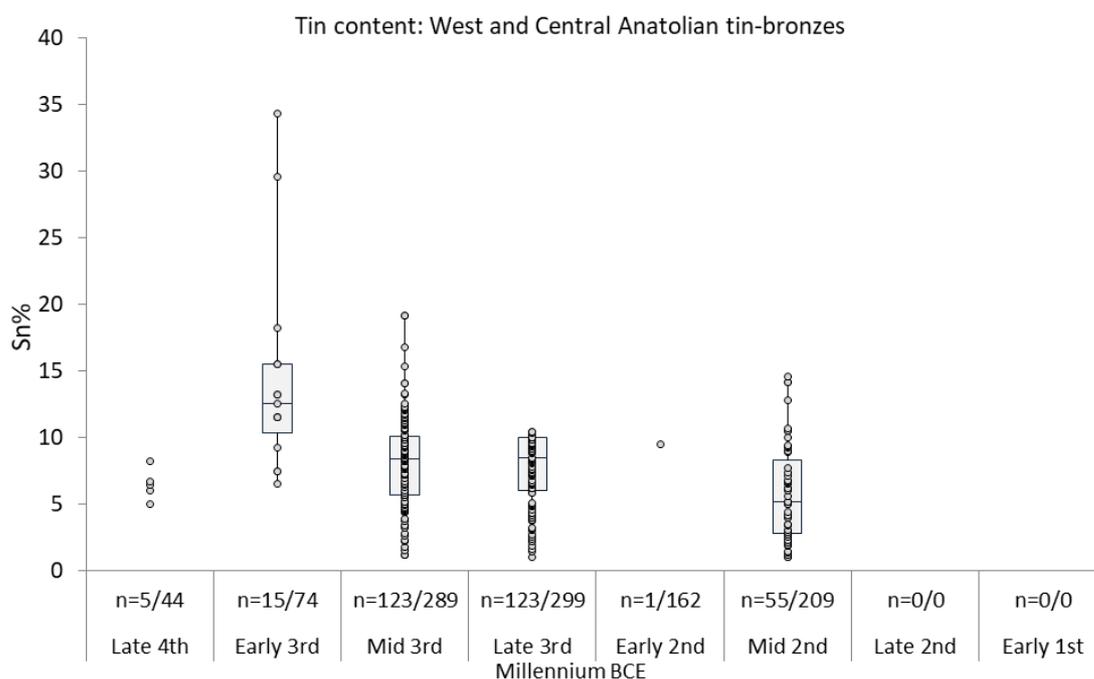


Figure 29: Box plot depicting tin content of all tin-bronzes (>1% Sn) from West and Central Anatolia

The mid-2nd millennium tin-bronze objects contain the lowest median tin content, but the maximum tin-content rises to around 15% in three objects. The decrease in tin content presents a similar picture to the decrease in the overall number of tin-

bronze objects during this period, and possibly reflects a change in metallurgical tradition or availability of tin as a material or ready-made objects via trade.

1.3 Copper Groups

From the late 4th millennium to the mid-2nd millennium BC, copper group 2 (As-only) is the most dominant copper composition in West and Central Anatolia, though it decreases slightly over this time from 57% of the assemblage to 42% (Table 6). The only time this is not the case is during the early 3rd millennium BCE, when just over 50% of the assemblage is made of copper group 16 ('all' – As, Sb, Ag and Ni), which is a unique occurrence in the entire region of Southwest Asia and through time. All of these objects have been found at Demircihüyük: this might reflect a period of experimentation of many ore sources mixed together, or perhaps this site being in possession of a different ore source from the rest of the region.

Table 6: Table depicting the entire West and Central Anatolian copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi	Total
Late 4th	0%	57%	0%	0%	0%	7%	0%	0%	14%	0%	9%	5%	0%	7%	2%	0%	44
Early 3rd	1%	7%	0%	0%	1%	5%	0%	0%	3%	4%	4%	1%	1%	4%	9%	58%	74
Mid 3rd	11%	45%	3%	2%	0%	10%	1%	0%	7%	0%	10%	2%	0%	4%	1%	1%	289
Late 3rd	6%	45%	0%	0%	1%	11%	0%	0%	6%	0%	20%	6%	0%	4%	1%	0%	299
Early 2nd	19%	44%	0%	6%	6%	13%	0%	0%	6%	0%	6%	0%	0%	0%	0%	0%	16
Mid 2nd	1%	42%	0%	0%	0%	18%	0%	0%	4%	0%	22%	0%	0%	8%	2%	2%	209
Late 2nd																	
Early 1st																	

From the early 3rd millennium BCE onwards there is an incremental increase of copper group 6 (AsSb) and a slightly more erratic increase of copper group 11 (AsNi) until both groups make up roughly a fifth of the assemblage. There are always two or three major copper groups (>10% of the assemblage) in use at one

time (apart from in the early 3rd millennium BCE) perhaps reflecting diversity of regional minerals or diversity of cultural contacts.

1.4 Arsenic, antimony, nickel, and silver content

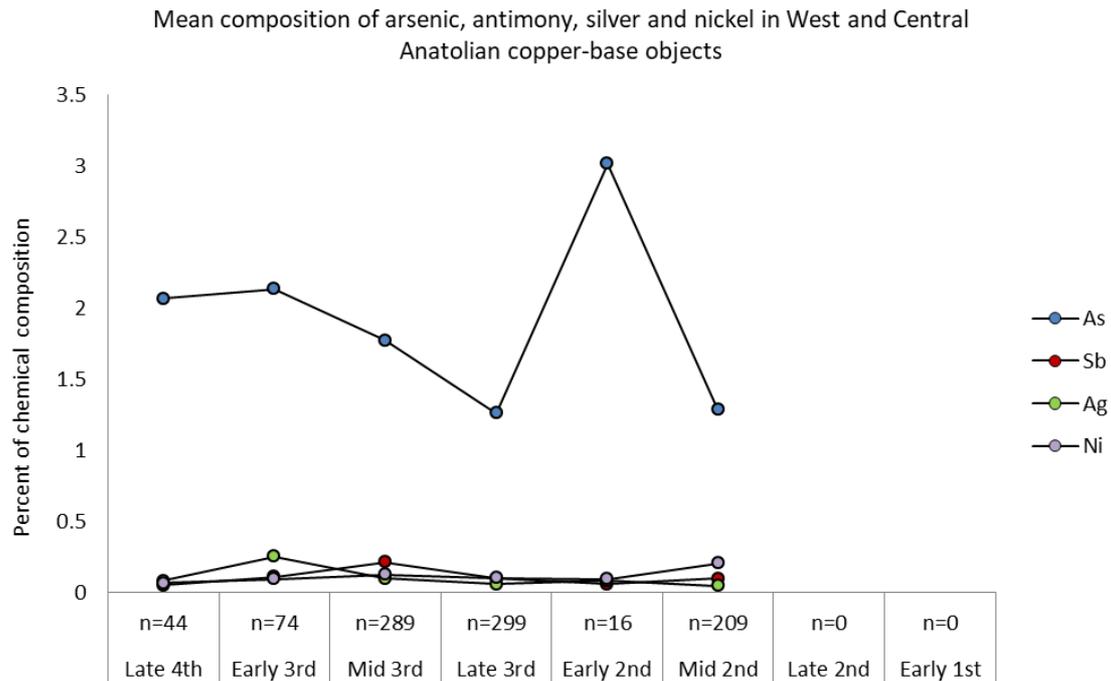


Figure 30: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from West and Central Anatolia

Between the late 4th millennium and mid-3rd millennium the maximum arsenic content increases from 8% to 14%. High arsenic copper is increasingly present in the region, but not representative of the bulk of each assemblage which contains between 0.1 and 2% arsenic. The mean arsenic content is much higher than that of antimony, silver or nickel (Figure 30) but decreases steadily from the late 4th millennium to the mid-2nd millennium, when Sb, Ag and Ni remain quite stable, though the average nickel content increases during the 2nd millennium BCE. From the late 3rd millennium to early 2nd millennium the average contents of both nickel

and arsenic increase by 0.1%, and this could suggest that there is an influx of copper containing both of these trace elements.

2 Eastern Anatolia

2.1 Bronze ubiquity

In comparison to most other regions of Southwest Asia, tin-bronze is rare in Eastern Anatolia throughout the Late Chalcolithic and Bronze Age; although the absolute amount of tin-bronze in use did increase slightly over time. It never accounted for more than 25% of the assemblage (Figure 31). There is a dramatic pattern change in the Iron Age, however, when 85% of the assemblage is made of tin-bronze. The use of tin-arsenic-bronze (>1% both As and Sn) is also minimal (Figure 32). Arsenical-bronze is generally more widely employed, though its use decreases from the mid-2nd millennium BCE (Figure 31). The ubiquity of unalloyed copper varies slightly through time but remains the dominant material. Looking at the relationships between materials, there is a consistently negative correlation between unalloyed and arsenical-bronze, which may be significant.

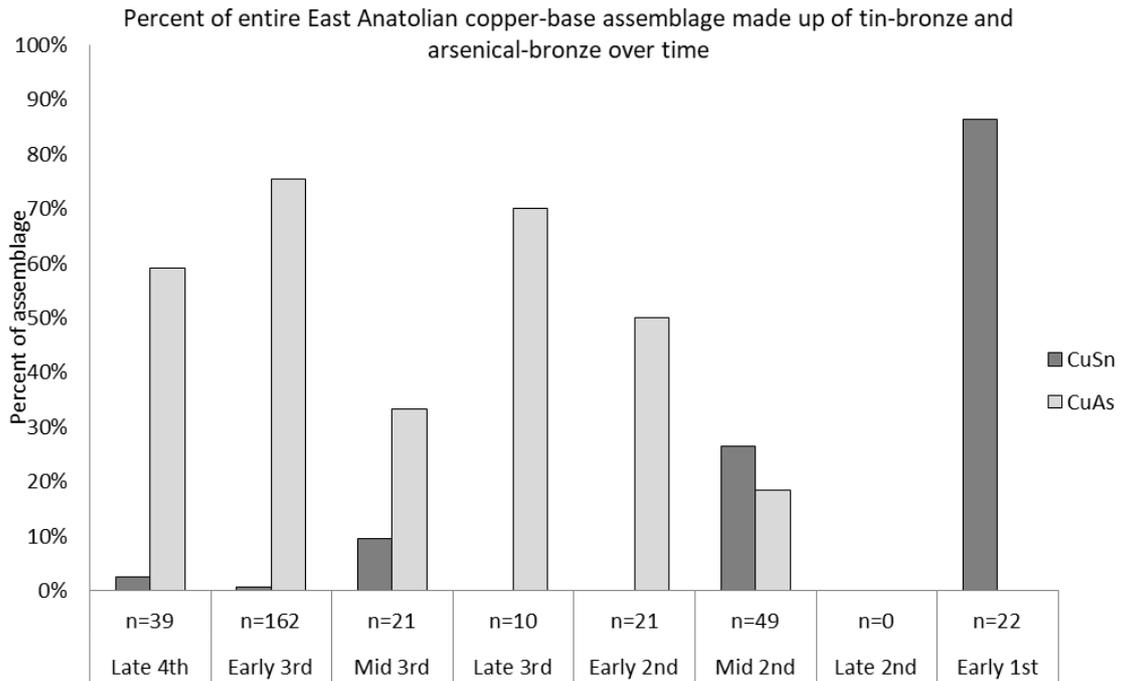


Figure 31: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in East Anatolia

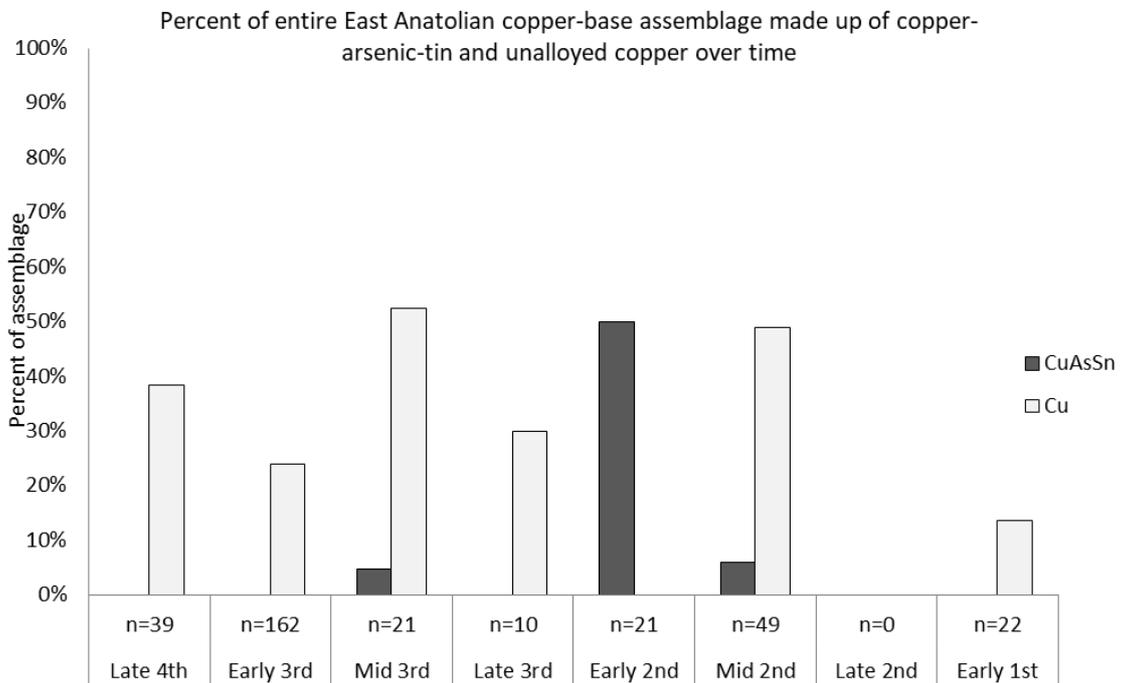


Figure 32: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in East Anatolia

2.1 Tin content

The tin content of all six tin-bronzes in Eastern Anatolia is generally low (c. 2% – 6.5% Sn) until the mid-2nd millennium BCE, from which point half the assemblage contains more than 5% Sn (Figure 33). Interpretations of this pattern must be treated with caution due to the limited sample sizes, though these may reflect the pattern of use themselves. In the early 1st millennium BCE the pattern is very similar to that of the mid-2nd millennium BCE, though there is a slight shift towards higher tin-contents.

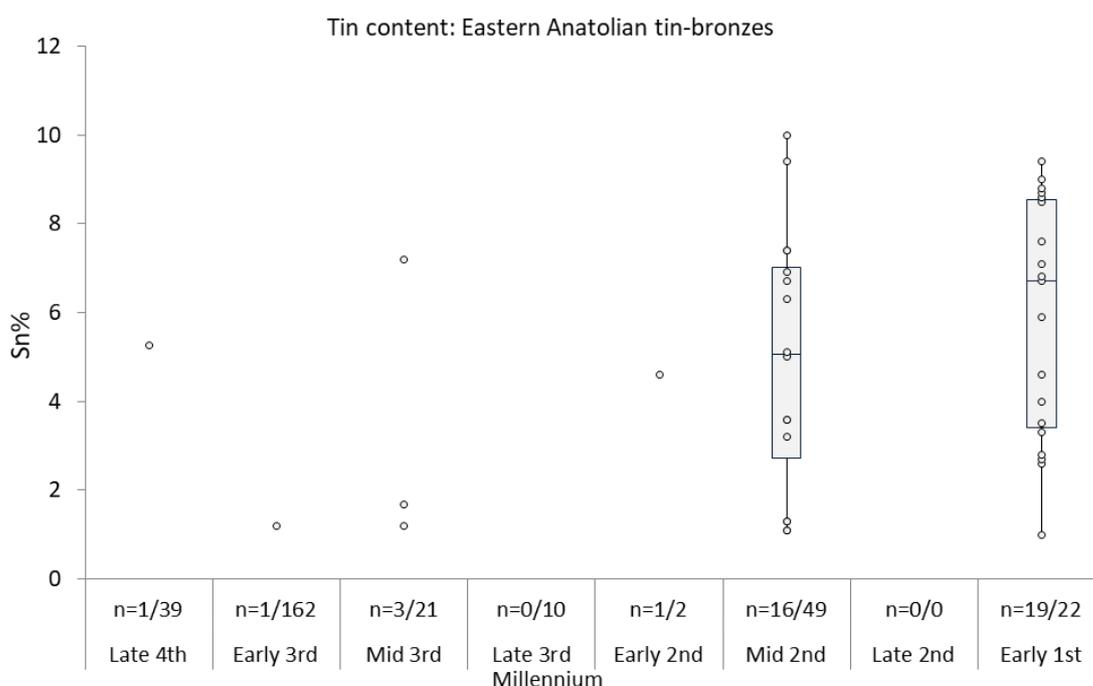


Figure 33: Box plot depicting tin content of all tin-bronzes (>1% Sn) from East Anatolia

2.2 Copper groups

A summary of the assemblages of Eastern Anatolia by period and copper group (Table 7) shows a number of potentially interesting patterns. The dominant copper composition in use is Group 2 (As only), with arsenic-nickel copper (Group11) as the second most abundant copper type. Clean copper (Group 1)

increases and decreases erratically over time, but twice makes up a third of the assemblage. In the early 1st millennium, when we see a change in tin-bronze use, we also see a complete change in copper group patterns – with almost two-thirds of the assemblage made of arsenic-antimony copper. There was more variation in copper composition during the late 4th millennium and early 3rd millennium BCE and a decrease in diversity throughout the 3rd millennium BCE.

Table 7: Table depicting the entire East Anatolian copper-base assemblage split into copper groups as designated by the ‘Oxford technique’. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi	Total
Late 4th	8%	33%	0%	3%	0%	3%	0%	0%	5%	3%	23%	0%	0%	18%	0%	5%	39
Early 3rd	5%	21%	1%	1%	1%	6%	1%	0%	6%	0%	27%	2%	0%	6%	13%	10%	162
Mid 3rd	33%	33%	0%	0%	14%	0%	0%	0%	0%	0%	0%	0%	0%	14%	5%	0%	21
Late 3rd	0%	70%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	10%	10%	0%	10
Early 2nd	0%	50%	0%	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2
Mid 2nd	33%	24%	4%	0%	8%	4%	0%	0%	0%	2%	16%	2%	0%	6%	0%	0%	49
Late 2nd																	
Early 1st	18%	9%	0%	5%	9%	59%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	22

2.3 Arsenic, antimony, nickel, and silver content

The average arsenic content of Eastern Anatolia’s copper assemblages varies substantially over time (Figure 34). The assemblage from the early 3rd millennium BCE in particular shows a general increase in arsenic content suggesting higher availability of arsenic-containing copper at this time. Here it is interesting to note that in comparison to mean values of arsenic, antimony, silver and nickel in the assemblages of West and Central Anatolia, the early Eastern Anatolian objects (late 4th to late 3rd millennium BCE) have higher average nickel values, between 0.3% and 0.7% Ni as well as higher silver values. From the early to mid-3rd millennium BCE the average concentrations of arsenic, nickel and silver drop, silver and nickel remain a similar pattern to one another potentially indicating a link between the

two elements. The average concentrations of antimony remain consistently low across the dataset (between 0% and 0.16%).

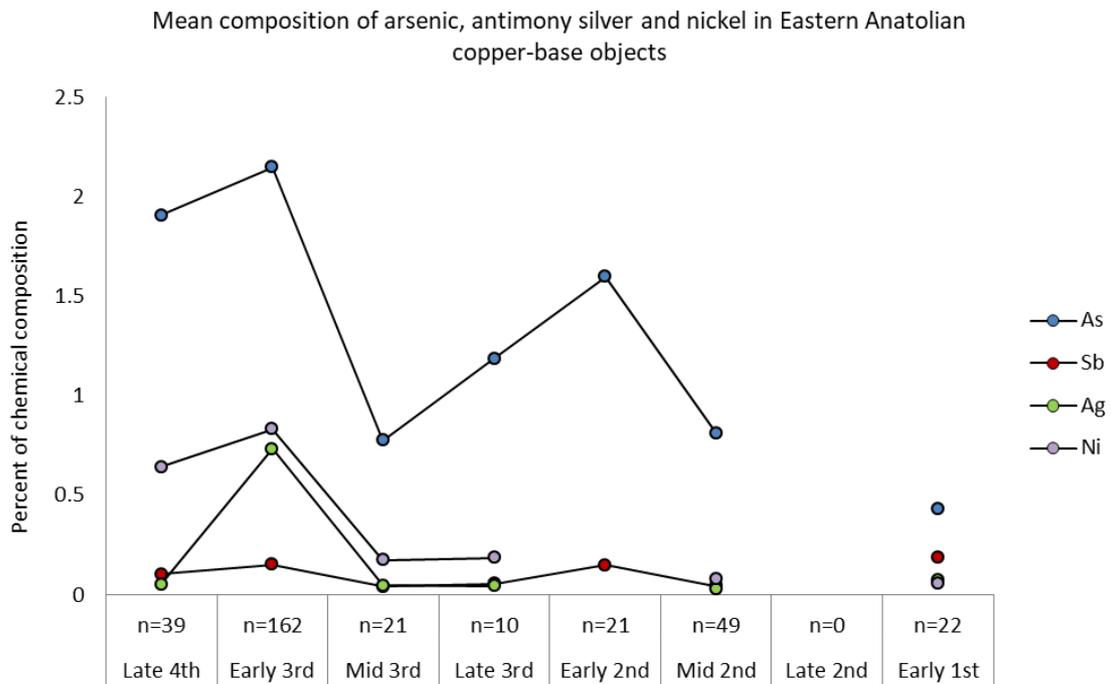


Figure 34: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from Eastern Anatolia

3 Southern Caucasus

3.1 Bronze ubiquity

The relationship between the use of tin-bronze and arsenical-bronze in the assemblages from the Southern Caucasus (Figure 35) conforms precisely to the traditional model for the development of a metallurgical tradition. While arsenical-bronze is most common in the early 3rd millennium BCE and shows a gradual decrease in use throughout the Bronze Age, the use of tin-bronze shows the inverse, with a corresponding increase in abundance over time. If taken together with the distribution of unalloyed copper and tin-arsenic-bronze (Figure 36), it is

evident that these alloys remain relatively consistent across the chronological range of this study, with only a slightly increasing trend in the abundance of mixed bronze into the mid-2nd millennium BCE.

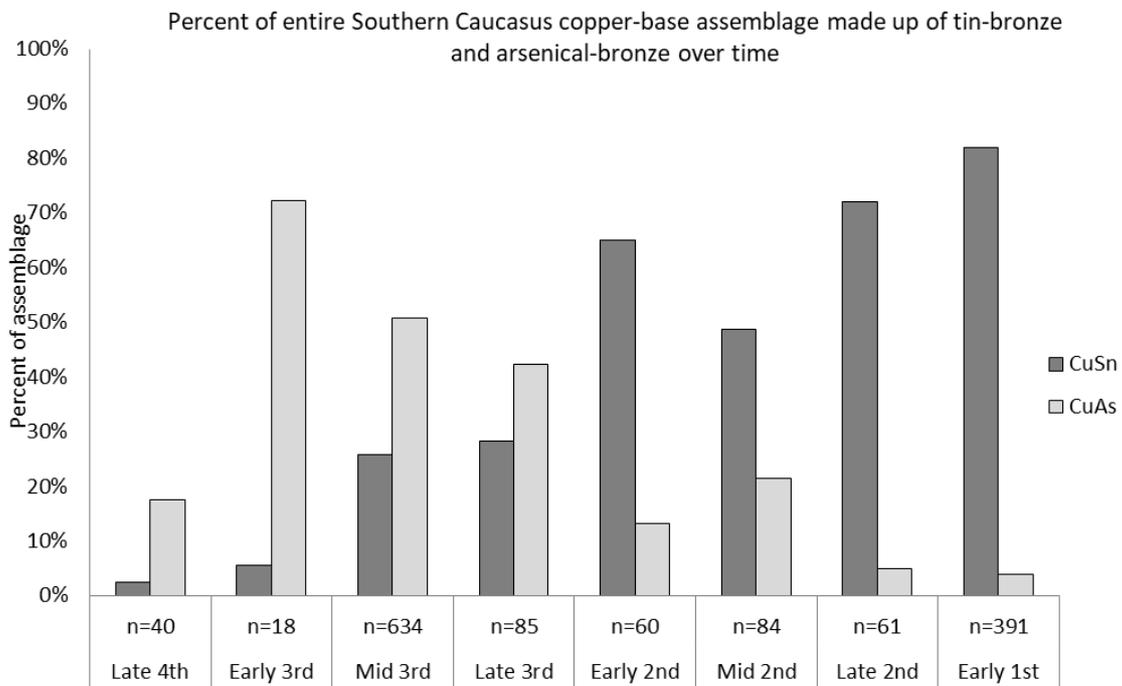


Figure 35: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in the Southern Caucasus

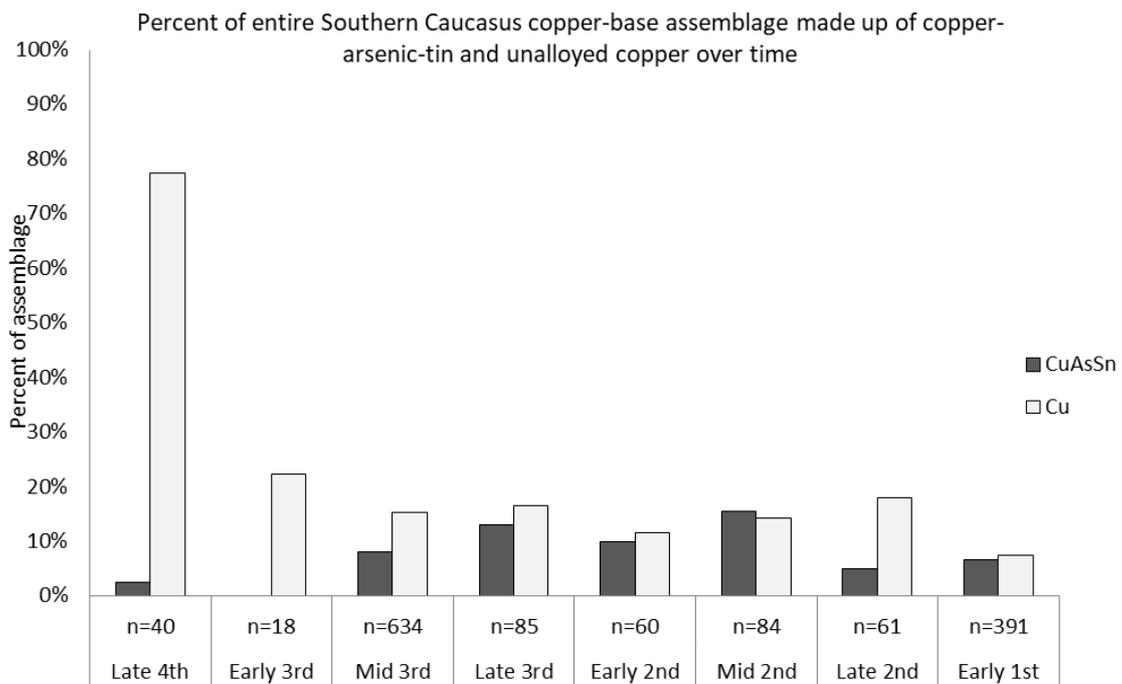


Figure 36: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in the Southern Caucasus

3.2 Tin content

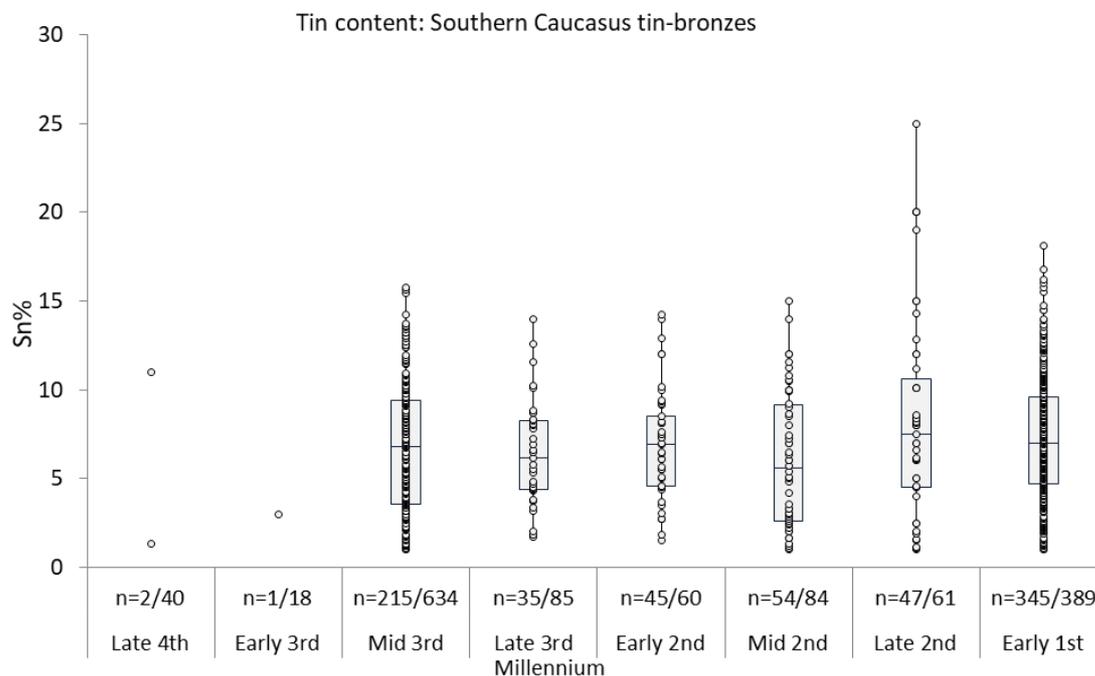


Figure 37: Box plot depicting tin content of all tin-bronzes (>1% Sn) from the Southern Caucasus

Though the amount of tin-bronze in use in the Southern Caucasus increases steadily throughout the 3rd millennium and 2nd millennium BCE, the average tin content within this alloy class remains relatively stable (

Figure 37). There is a slight increase, both in maximum and median values, moving into the late-2nd millennium BCE, but these fall back again by the early 1st millennium BCE. The tin-bronzes from the Caucasus represent the most visually stable tin-industry in comparison to the rest of Southwest Asia.

3.3 Copper Groups

As in Anatolia, arsenic-only (Group 2) is the dominant copper composition in the assemblages from the late 4th millennium to the early 2nd millennium BCE, and is

one of the dominant groups from the mid-2nd millennium to late 1st millennium though diminishing slightly (Table 8). Conversely, the second most significant group, arsenic-antimony (Group 6), becomes gradually more prominent over time – becoming the most commonly represented copper group by the mid-2nd millennium BCE, but also decreasing from the late 2nd millennium BCE onwards, as the copper signal in the early 1st millennium becomes much more diverse and scattered across various copper compositions.

Table 8: Table depicting the entire Southern Caucasus copper-base assemblage split into copper groups as designated by the ‘Oxford technique’. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAg	AsSb	AsAg	AsSbAg	Total
												g	Ni	Ni	Ni	gNi	
Late 4th	3%	3%	0%	5%	0%	3%	10%	0%	13%	0%	3%	58%	0%	3%	3%	0%	40
Early 3rd	11%	61%	0%	0%	0%	6%	0%	6%	11%	0%	6%	0%	0%	0%	0%	0%	18
Mid 3rd	19%	35%	5%	0%	1%	17%	0%	0%	9%	0%	3%	3%	0%	1%	6%	1%	634
Late 3rd	7%	48%	0%	2%	0%	20%	0%	0%	7%	0%	5%	2%	0%	2%	6%	0%	85
Early 2nd	12%	57%	3%	3%	0%	8%	2%	0%	2%	0%	7%	0%	0%	3%	3%	0%	60
Mid 2nd	6%	27%	0%	0%	4%	37%	0%	0%	4%	0%	5%	2%	0%	13%	1%	1%	84
Late 2nd	13%	38%	2%	7%	2%	23%	0%	0%	10%	0%	3%	2%	0%	2%	0%	0%	61
Early 1st	11%	22%	2%	6%	2%	20%	1%	1%	13%	1%	2%	7%	0%	12%	1%	0%	389

3.4 Arsenic, antimony, nickel, and silver content

Mean composition of arsenic, antimony, silver and nickel in Southern Caucasus copper-base objects

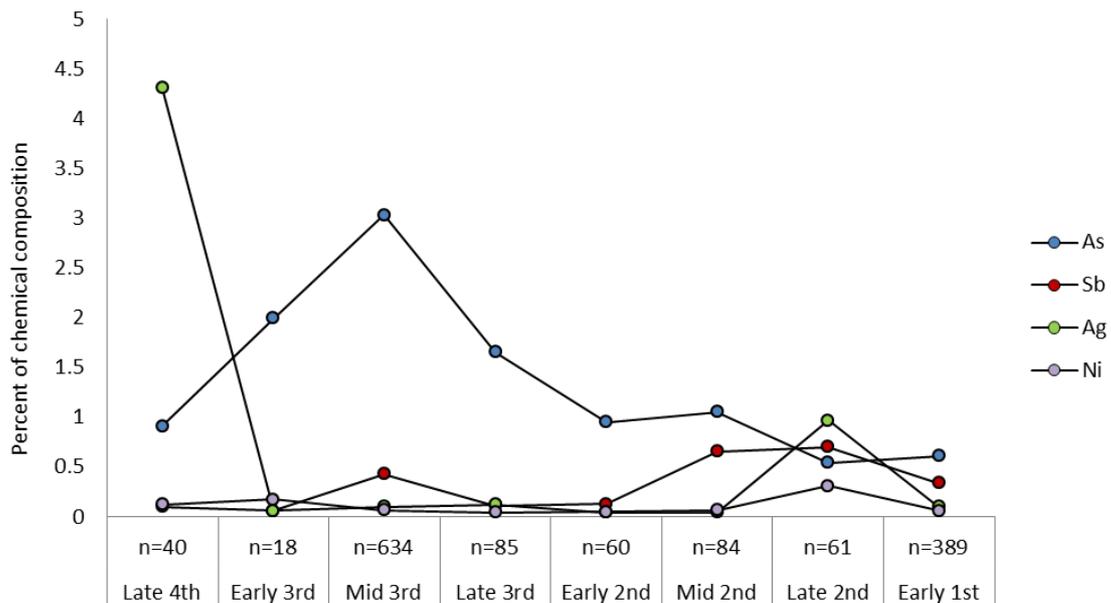


Figure 38: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from the Southern Caucasus

Although the most characteristic trend in average elemental composition is a decrease in average arsenic content over time (Figure 38), it is worth noting a number of other patterns. Antimony, silver and nickel are present only in low amounts (c. 0.03% – 0.2%) until the mid-2nd millennium BCE when the average antimony content appears to rise (c. 0.6% Sb). Similar increases in nickel and silver content are seen in the late 2nd millennium BCE. The average values for all three of these elements subsequently fall in the early 1st millennium BCE, but copper compositions containing low levels of these elements remain in use at least until the end of the study period. The average concentrations of these elements indicate a significant regional difference from neighbouring regions, and possibly differing mineralisation of the region.

4 Northern Caucasus

4.1 *Bronze ubiquity*

Copper alloy use in the Northern Caucasus remains very consistent from the late 4th millennium to the mid-2nd millennium BCE, when arsenical-bronze use decreases and tin-bronze becomes more common (Figure 39). Tin-bronze only amounts to 3% of the assemblage in the late 3rd millennium BCE and jumps to a third of the assemblage in the mid-2nd millennium BCE. It is only in the early 1st millennium that tin-bronze is the dominant alloy in the region. Unalloyed copper only shows any real presence from the mid-2nd millennium BCE onwards, and copper-arsenic-tin hovers at 7% of the assemblage during this time (Figure 40). This pattern indicates some form of change or disruption in the metallurgical

tradition from the middle of the 2nd millennium BCE, after which more changes in alloy use occur.

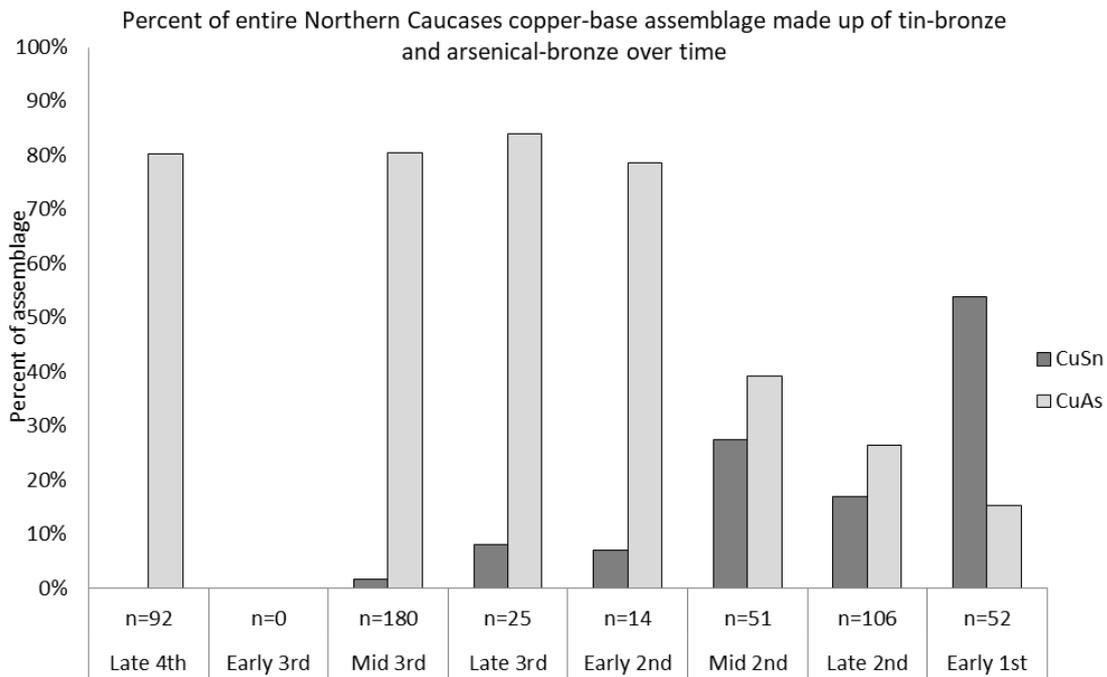


Figure 39: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in the Northern Caucasus

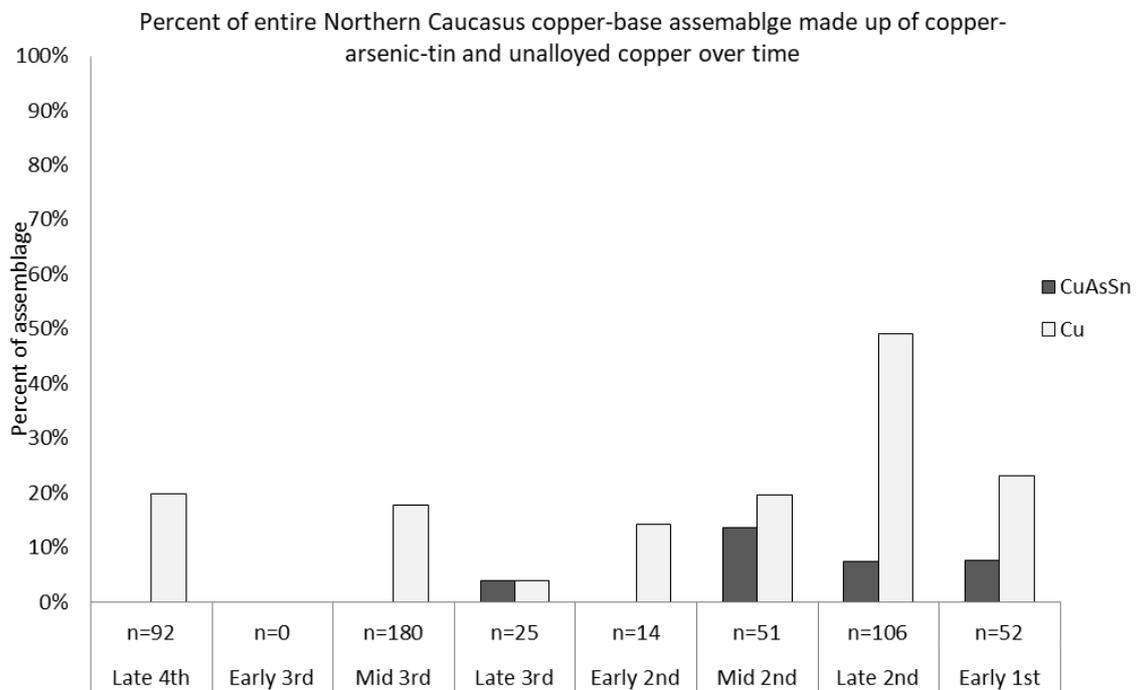


Figure 40: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in the Northern Caucasus

4.2 Tin content

The three tin-bronzes from the late 3rd millennium BCE, all of which came from the same site of Velikent, contain between 12% and 12.7% Sn, the same values which constitute the upper end of tin content in later assemblages (Figure 41). From the mid-2nd to early 1st millennium BCE the range of tin composition is similar through time (c. 1%- 14%), the median content ranges from 4 to 9% Sn. The early 4th to early 2nd millennium BCE indicates very limited access to tin or tin-bronze, but the latter three periods could show some stability of access, reflecting the pattern seen in ubiquity of tin bronze objects as displayed in Figure 39.

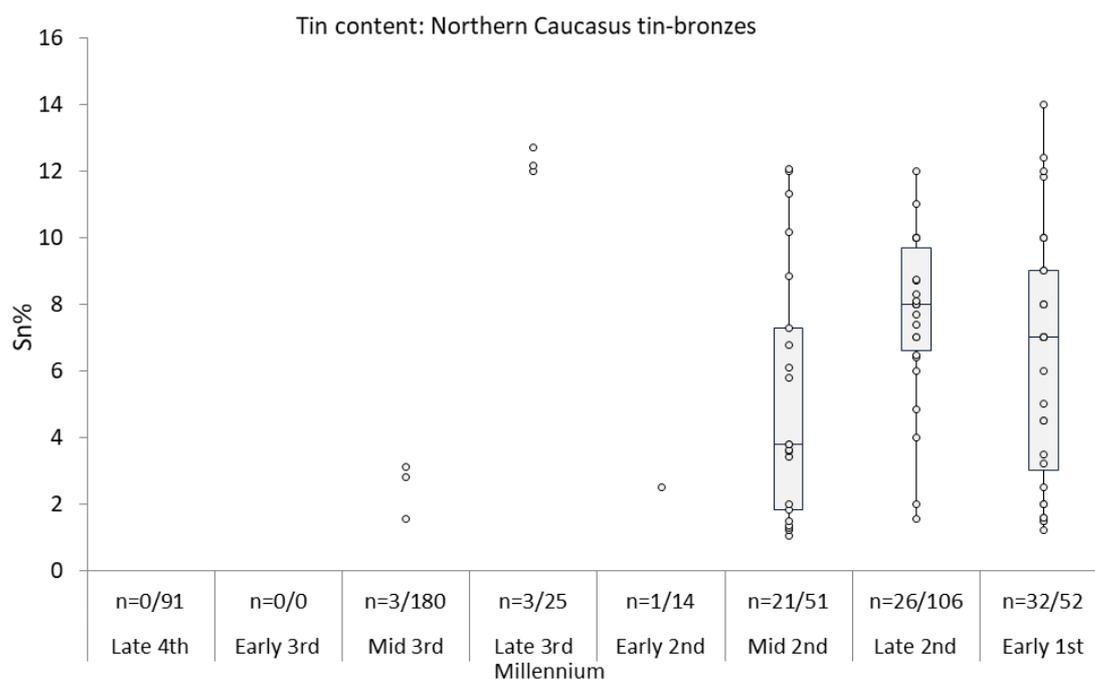


Figure 41: Box plot depicting tin content of all tin-bronzes (>1% Sn) from the Northern Caucasus

4.3 Copper Groups

Arsenic-only copper is the most ubiquitous copper composition from the late 4th millennium to the mid-2nd millennium BCE, after which point it decreases to only 11% of the assemblage in the late 2nd millennium (Table 9). From the early 2nd

millennium onwards groups containing antimony become more prominent in the assemblage, once more indicating some form of change in the region. ‘Clean’ copper also increases in from the mid-2nd onwards from 4% of the assemblage to 13%. Around the mid-2nd millennium onwards we also see a jump in copper group diversity and this continues to increase up to a diversity of 12 out of 16 groups in the late 2nd millennium BCE, again indicating an apparent change in metallurgical tradition in the latter half of the 2nd millennium onwards.

Table 9: Table depicting the entire Northern Caucasus copper-base assemblage split into copper groups as designated by the ‘Oxford technique’. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi	Total
Late 4th	1%	57%	0%	0%	0%	0%	0%	0%	0%	0%	33%	0%	0%	1%	8%	0%	91
Early 3rd																	
Mid 3rd	2%	84%	1%	0%	0%	8%	0%	0%	1%	0%	2%	1%	0%	1%	0%	1%	180
Late 3rd	0%	76%	0%	0%	0%	0%	0%	0%	4%	0%	12%	0%	0%	0%	4%	4%	25
Early 2nd	7%	71%	0%	0%	7%	14%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	14
Mid 2nd	4%	41%	6%	0%	0%	18%	0%	0%	6%	0%	10%	2%	0%	12%	2%	0%	51
Late 2nd	9%	11%	23%	0%	0%	8%	6%	0%	3%	1%	5%	15%	1%	0%	5%	13%	106
Early 1st	13%	21%	4%	0%	2%	40%	4%	0%	2%	0%	6%	2%	0%	4%	0%	2%	52

4.4 Arsenic, antimony, nickel, and silver content

The gradual decrease in average arsenic content from the late 3rd millennium BCE and the sharp increase in average antimony content beginning in the early 2nd millennium BCE as mentioned in the previous section is clearly seen in Figure 42. As antimony hits its peak average content, there is also a corresponding rise in silver content suggesting a link between the two elements.

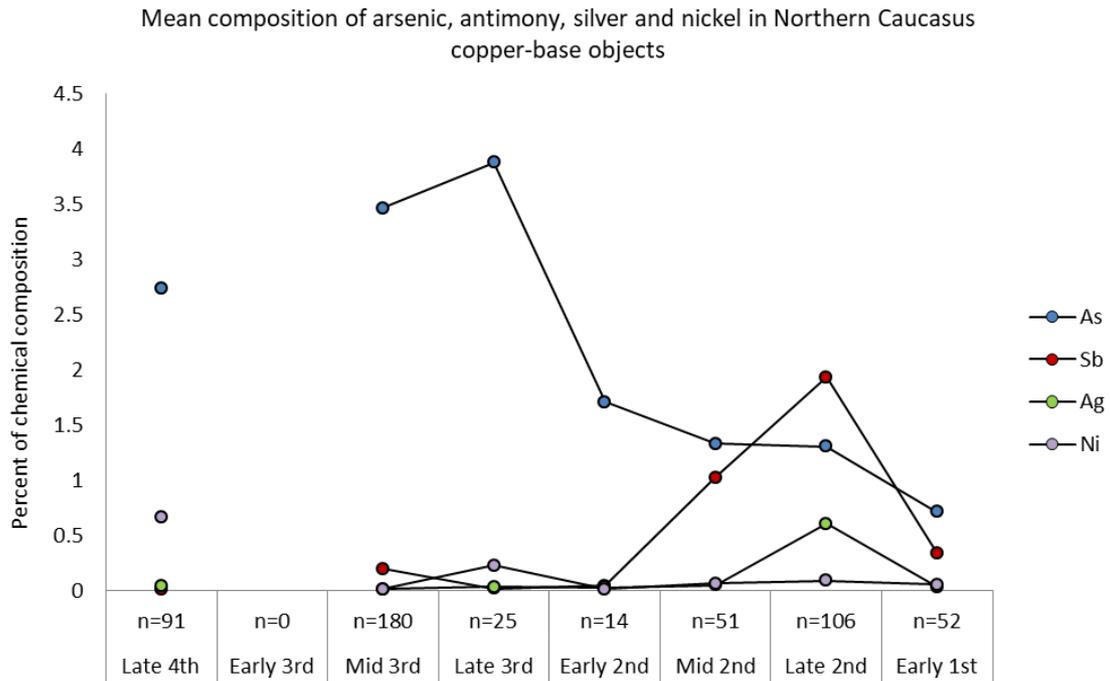


Figure 42: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from the Northern Caucasus

5 Mediterranean Coast

5.1 Bronze ubiquity

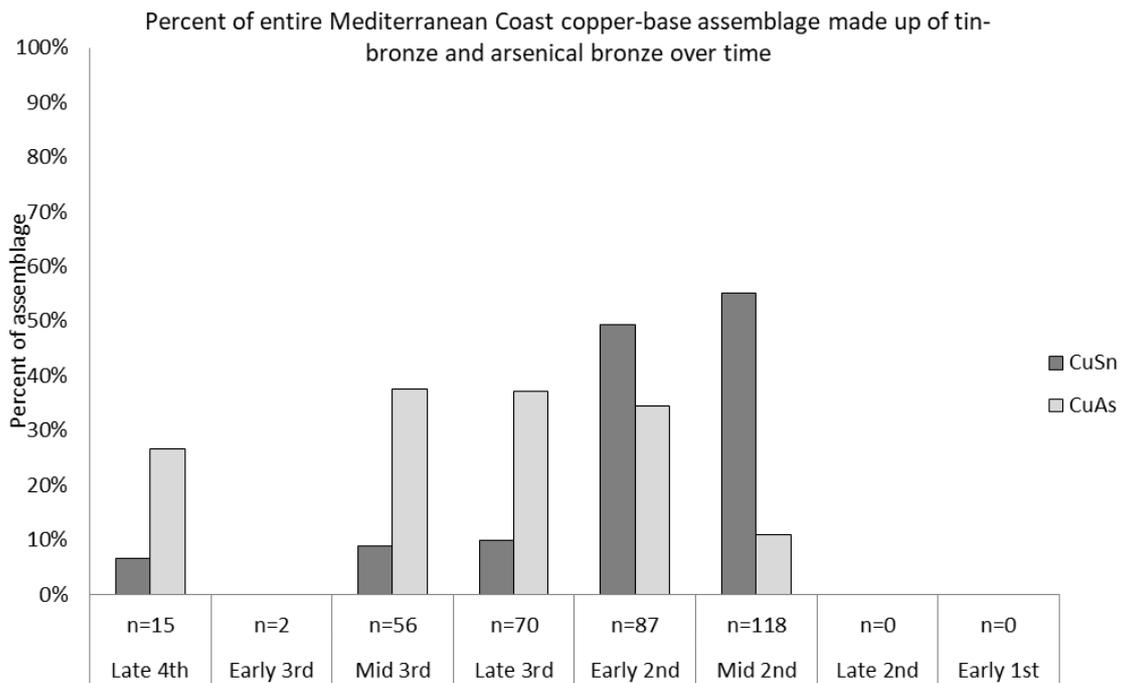


Figure 43: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in the Mediterranean Coast

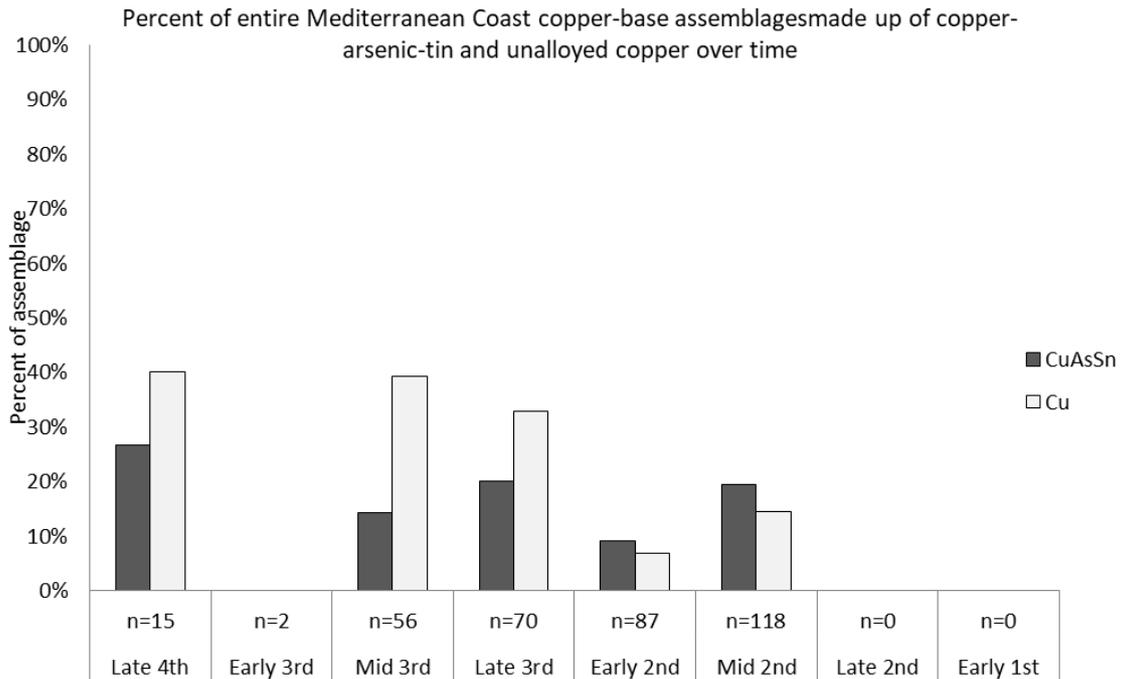


Figure 44: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in the Mediterranean Coast

Arsenical-bronze consistently makes up between 25% and 40% of the Mediterranean Coast copper-base assemblage from the late 4th millennium BCE until the early 2nd millennium BCE (Figure 43), after this point tin-bronze usage increases dramatically and becomes the dominant alloy, though arsenical-bronze is still very much in use. In the mid-2nd millennium BCE arsenical-bronze almost disappears and tin-bronze use increases. The early 2nd millennium BCE therefore appears to be a transition period between two bronze-types. Unalloyed copper decreases during this transition period, as does copper-arsenic-tin (Figure 44) suggesting that tin is added to unalloyed copper rather than arsenical-bronze. This appears to change in the mid-2nd millennium BCE when a decrease in arsenical-bronze occurs with an increase in copper-arsenic-tin alloy use – possibly indicating a move towards adding tin to local arsenic-rich copper, rather than ready-made tin-bronze imports.

5.2 Tin content

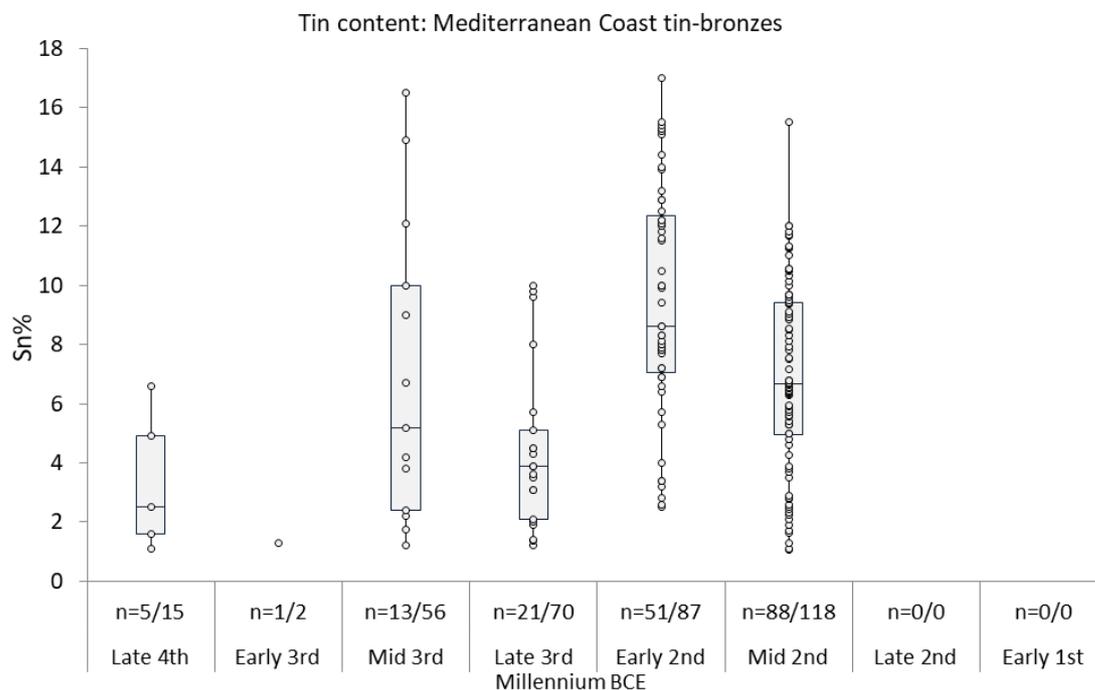


Figure 45: Box plot depicting tin content of all tin-bronzes (>1% Sn) from the Mediterranean Coast

The median tin content of tin-bronzes in the Mediterranean Coast region is exceptionally low in comparison to the surrounding regions until the early 2nd millennium BCE (Figure 45). The median content in the late 4th millennium is 2.2% Sn, with the maximum value reaching 6.5% Sn. In the early 3rd millennium BCE, the only tin-bronze object contains 1.75% tin. The tin contents of the mid-3rd millennium BCE display quite a range, from 1% to 17% Sn, but half the objects contain less than 4% Sn. In the late 3rd millennium BCE both the range of tin composition and median value decrease. As in the patterns of tin-bronze ubiquity, there is a shift in object tin content in the early 2nd millennium BCE – the median jumps to 8% Sn, and a third of the objects contain between 11% and 18% Sn. The overall range of tin content in the mid-2nd millennium BCE ranges from 1% to 12%

Sn; these values could indicate quite a varied or de-centralised approach to the tin-bronze industry, or fluctuating access to resources.

5.3 Copper Groups

The pattern of copper group use in the Mediterranean Coast region is very variable; with no one copper group showing clear dominance for any long period of time (Table 10). There are four major copper groups which are in use simultaneously, but which are consistently derived from the same three elements: arsenic-only, arsenic-antimony, arsenic-nickel and arsenic-antimony-nickel. It is interesting to note that neither antimony nor nickel is ever present without the corresponding presence of arsenic. When arsenic-antimony-nickel almost completely disappears from the record (mid-2nd millennium BCE) there is also a decrease in both arsenic-antimony and arsenic-nickel and an increase in arsenic-only. There is also the introduction of arsenic-silver and, and an increase in the diversity of copper groups present, most of which now contain >0.1% silver, suggesting a change either in production or source of material.

Table 10: Table depicting the entire Mediterranean Coast copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAg	AsSb	AsAg	AsSbAg	Total
Late 4th	0%	20%	0%	0%	0%	7%	0%	0%	7%	0%	7%	0%	0%	47%	7%	7%	15
Early 3rd	0%	0%	0%	0%	0%	0%	0%	0%	50%	0%	50%	0%	0%	0%	0%	0%	2
Mid 3rd	5%	20%	0%	0%	2%	23%	0%	0%	2%	0%	23%	4%	0%	18%	2%	2%	56
Late 3rd	3%	21%	0%	0%	0%	19%	0%	0%	1%	0%	21%	3%	0%	26%	3%	3%	70
Early 2nd	37%	46%	0%	6%	0%	3%	0%	0%	2%	0%	3%	0%	0%	1%	1%	0%	87
Mid 2nd	7%	43%	0%	2%	0%	14%	0%	1%	11%	0%	14%	2%	0%	3%	3%	1%	118
Late 2nd																	
Early 1st																	

5.4 Arsenic, antimony, nickel, and silver content

Antimony and nickel are present in much higher quantities in the Mediterranean Coast assemblages than any of its more northerly neighbours until after the end of the 3rd millennium BCE (Figure 46). Though the early 2nd millennium assemblage ought to be treated cautiously, this decrease in the mean antimony and nickel contents is also reflected in the late 2nd millennium assemblage, which contains just over one hundred objects.

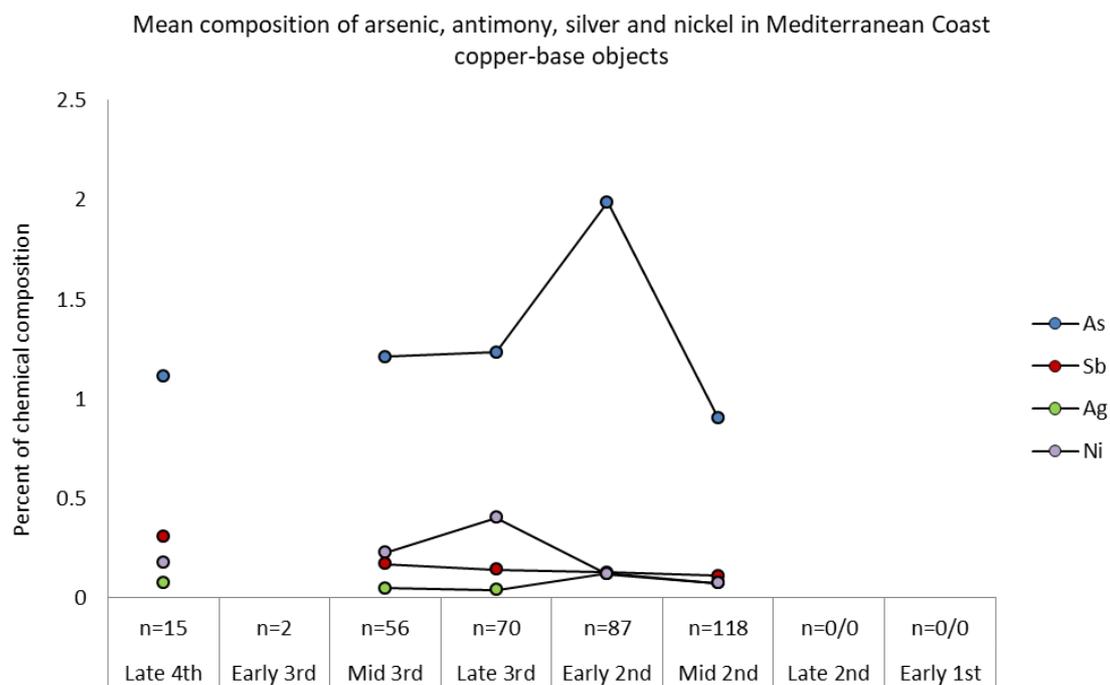


Figure 46: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from the Mediterranean Coast (3 outliers containing high silver removed - 61.5, 59.4 and 57.7)

6 Cyprus

6.1 Bronze ubiquity

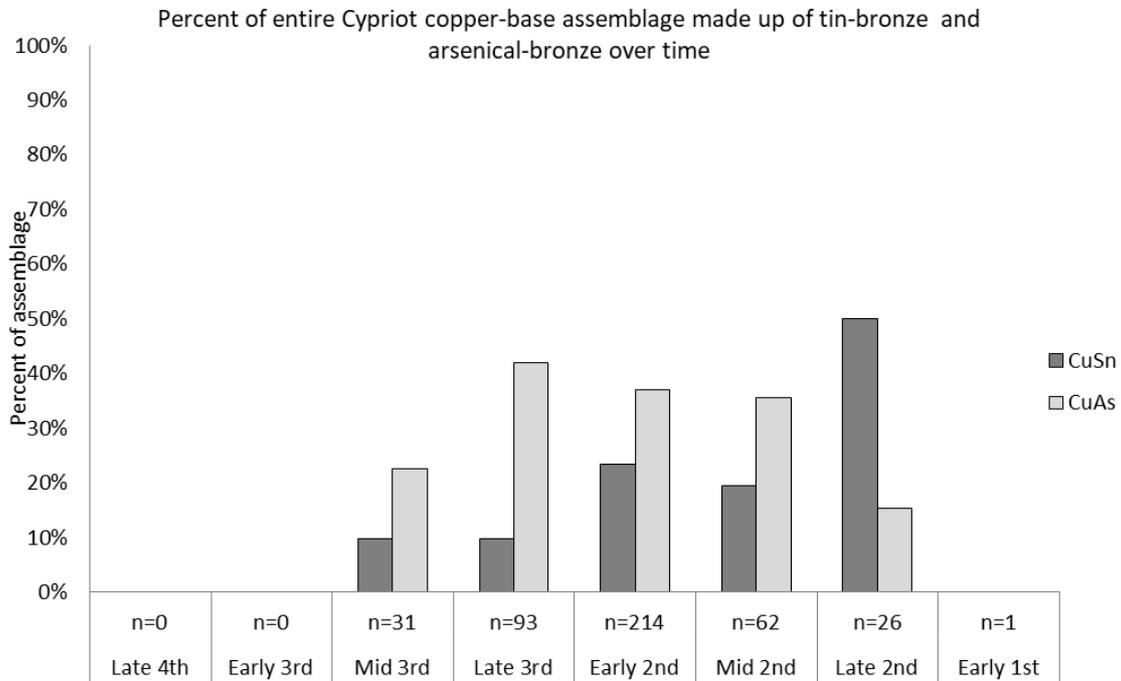


Figure 47: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in Cyprus

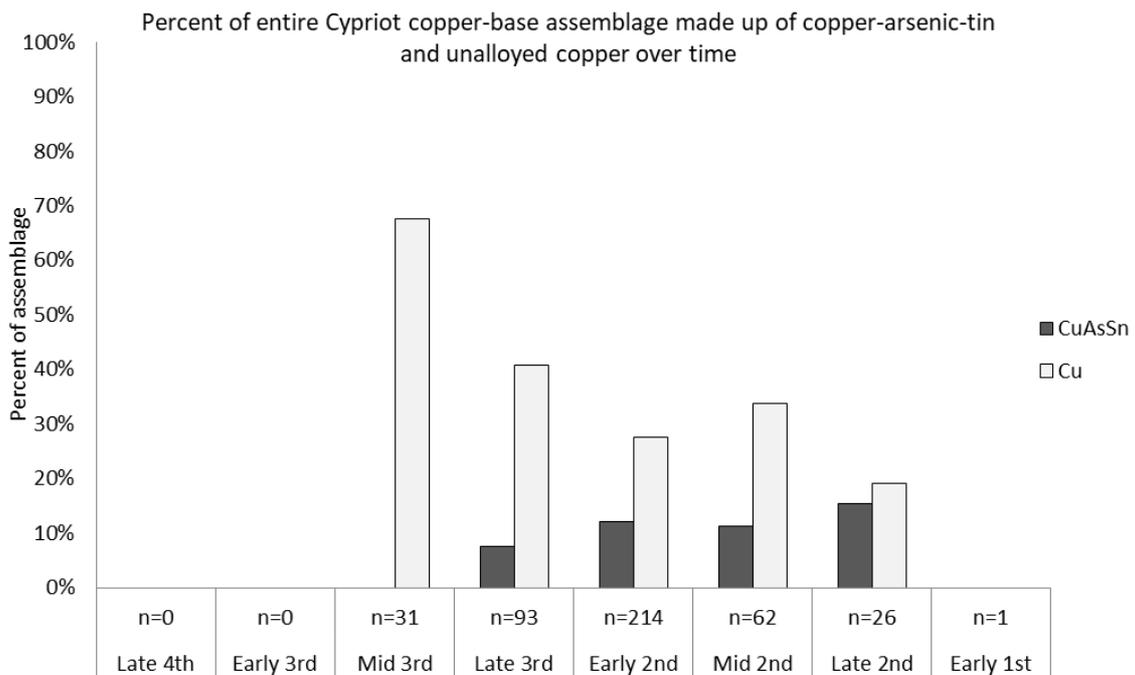


Figure 48: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in Cyprus

Tin-bronze ubiquity in Cyprus from the mid-3rd millennium BCE to the mid-2nd millennium BCE is relatively low, at most reaching less than a quarter of the overall assemblage (Figure 47), but it is considerably more consistent than in the Mediterranean region, Eastern Anatolia and the Southern Caucasus. It is only in the late 2nd millennium BCE that more than half the assemblage contains tin, unlike in the neighbouring trading region of the Mediterranean Coast. As Cyprus is an island with no known tin sources, and was relatively isolated until the 2nd millennium BCE, it is unexpected to find that there was a continuous tin-bronze presence over time. Copper-arsenic-tin alloy use increases from the late 3rd to the late 2nd millennium BCE (Figure 48), as arsenical-bronze decreases which could suggest that tin or tin-bronze was being added to the arsenical-bronze.

6.2 *Tin content*

The range of tin content in all tin-bronze objects from the late 3rd millennium to the late 2nd millennium in Cyprus (the three objects from the mid-3rd millennium BCE contain 9.87%, 12.24% and 12.52% Sn) wavers from a 13% range in the late 3rd millennium to a 29% range in the early 2nd when there are seven objects with more than 15% tin (Figure 49). During the mid-2nd millennium BCE the maximum tin content decreases to 15% Sn, and in the late 2nd millennium rises once more to 23% Sn, though there are only two objects with more than 15% tin content. The metallurgical tradition in Cyprus appears to be consistently varied, perhaps displaying a continuous tradition of recycling throughout the Bronze Age, due to a

lack of consistent access to raw materials, alongside sporadic importation of higher tin-bronze objects.

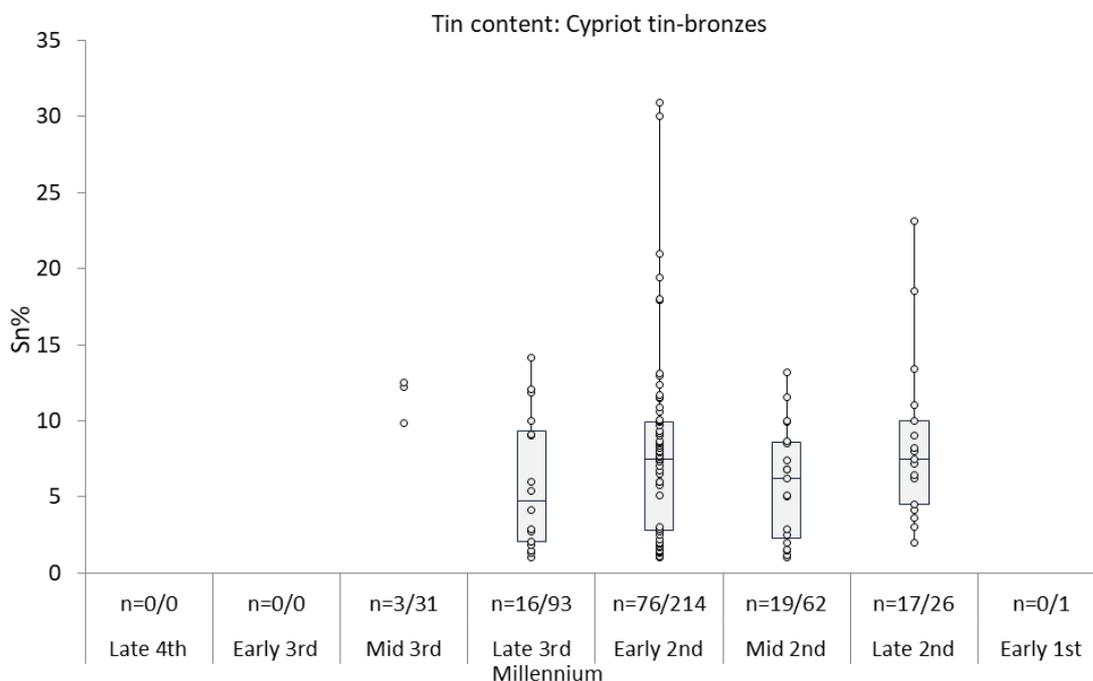


Figure 49: Box plot depicting tin content of all tin-bronzes (>1% Sn) from Cyprus

6.3 Copper Groups

Table 11: Table depicting the entire Cypriot copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAg Ni	AsSb Ni	AsAg Ni	AsSbAgNi	Total
Late 4th																	
Early 3rd																	
Mid 3rd	55%	32%	3%	0%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	31
Late 3rd	19%	65%	2%	0%	0%	3%	0%	0%	2%	0%	9%	0%	0%	0%	0%	0%	93
Early 2nd	29%	57%	0%	0%	3%	5%	0%	0%	4%	0%	1%	0%	0%	0%	0%	0%	214
Mid 2nd	16%	56%	2%	0%	6%	11%	0%	0%	6%	0%	0%	0%	0%	0%	0%	2%	62
Late 2nd	12%	46%	0%	0%	0%	4%	0%	0%	4%	0%	35%	0%	0%	0%	0%	0%	26
Early 1st	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1

Cypriot copper from the mid-3rd millennium to the mid-2nd millennium BCE is almost exclusively made up of the arsenic-only and 'clean' copper groups (Table 11). The amount of 'clean' copper in use decreases throughout this time period

with a brief increase in the early 2nd millennium. From the late 3rd millennium BCE onwards the amount of arsenic-only copper in use also decreases but is always the dominant copper group in use. In the late 2nd millennium there is an influx of arsenic-nickel copper, making it the second most common copper group in use during this period. There is more diversity of copper groups in the early 2nd millennium BCE, but in most cases the presence of other copper groups is insignificant in comparison to ‘clean’ copper and arsenic-only copper, once more reflecting the relative isolation of the region.

6.4 Arsenic, antimony, nickel, and silver content

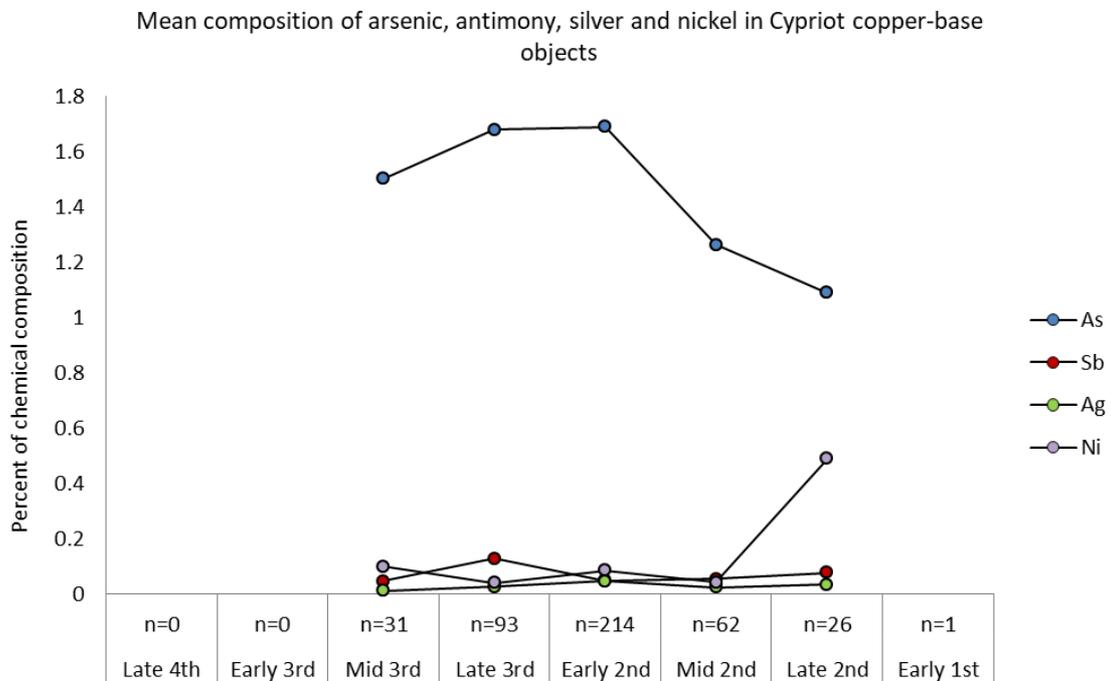


Figure 50: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from Cyprus

As with West and Central Anatolia the mean arsenic content is much higher than the averages of antimony, silver and nickel, which all remain consistently low, though the average content of nickel increases in the late 2nd millennium BCE when there is an influx of arsenic-nickel copper (Figure 50). The mean arsenic content decreases from the late 3rd millennium BCE onwards, perhaps indicative of a recycling of arsenic-rich objects.

7 Southern Levant

7.1 *Bronze ubiquity*

The metallurgical tradition in the Southern Levant was different from that of any other region in Southwest Asia (Figure 51 and Figure 52). Unalloyed copper was the dominant alloy-type throughout the 3rd millennium BCE, followed by arsenical-bronze which increases to account for a third of the entire assemblage by the late 3rd millennium. Tin-bronze and copper-arsenic-tin alloy first appear in the late 3rd millennium BCE, though both alloy-types together amount to just under 15% of the assemblage. In the early and mid-2nd millennium tin-bronze becomes the dominant alloy. Arsenical-bronze continues to account for a third of the assemblage throughout the 2nd millennium, and tin-bronze appears to directly replace unalloyed copper. In the mid-2nd millennium both unalloyed copper and tin-bronze increase while arsenical-bronze continues to decrease until it disappears in the

early 1st millennium BCE. In the late 2nd and early 1st millennium unalloyed copper becomes the dominant alloy once again, and tin-bronze makes up the remainder. The metallurgical tradition in this region can be split into three phases: the first (from the late 4th to mid-3rd millennium BCE) is dominated by the use of unalloyed copper, with supplementary arsenical-bronze use; the second (late 3rd millennium to mid-2nd millennium BCE) indicates variation between almost equal amounts of tin-bronze, arsenical-bronze and unalloyed copper; and the third (late 2nd millennium to early 1st millennium BCE) a return to predominant use of unalloyed copper supplemented by tin-bronze use rather than arsenical-bronze.

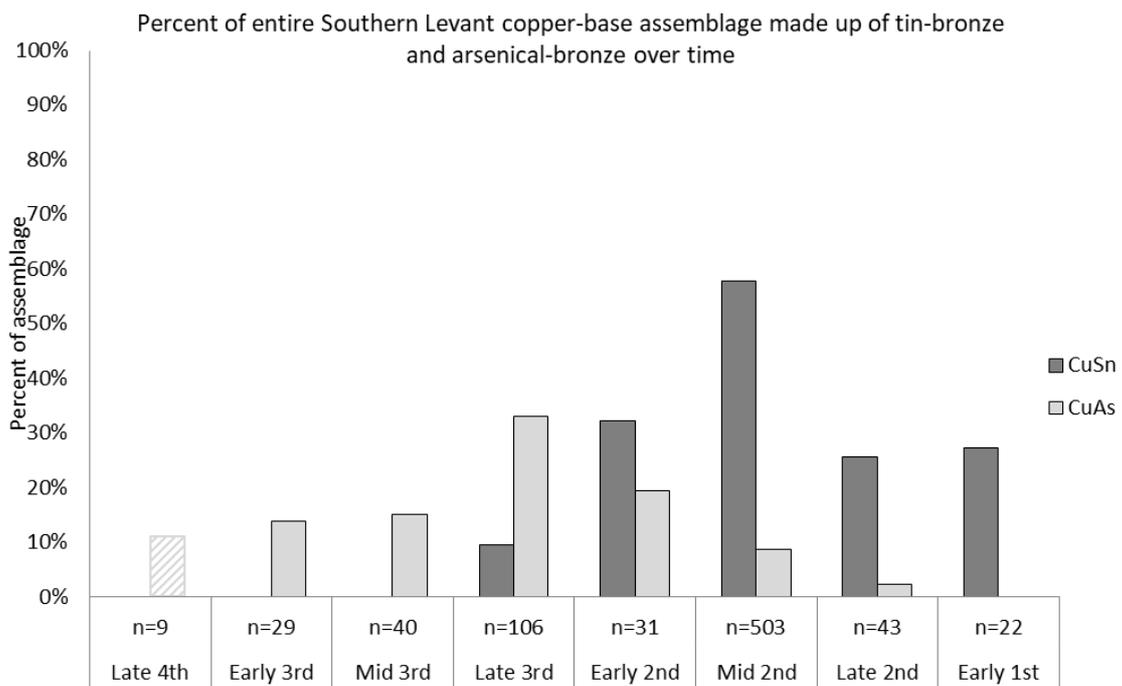


Figure 51: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in the Southern Levant

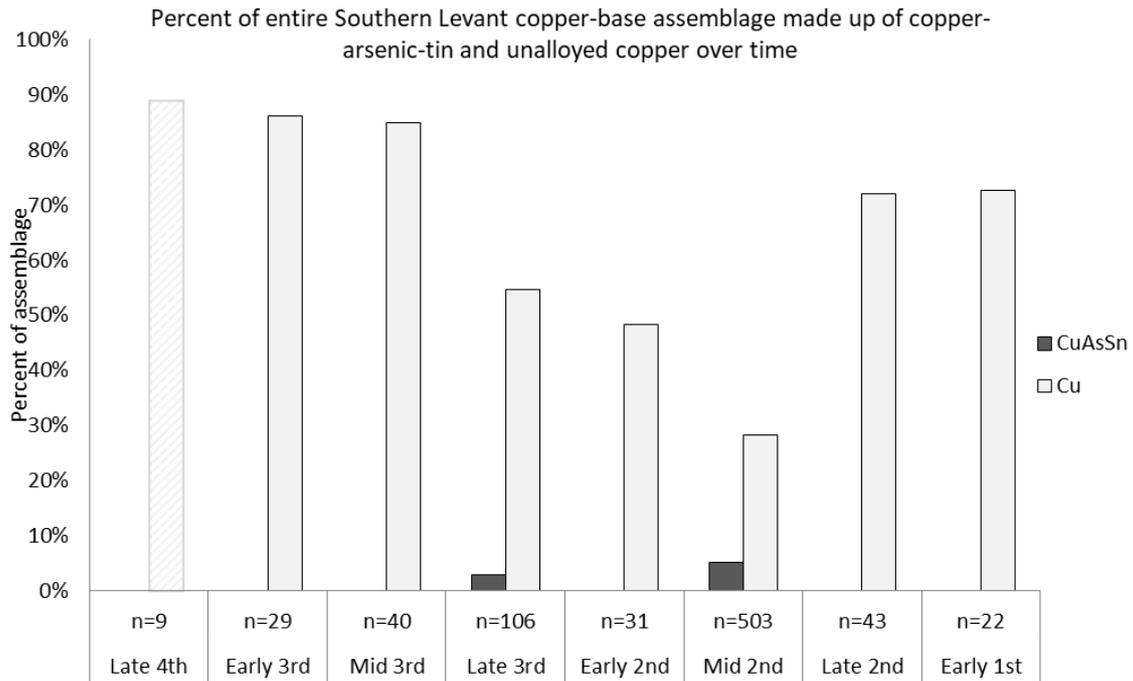


Figure 52: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in the Southern Levant

7.2 Tin content

The most striking feature of the average tin content in the Southern Levant is an apparent decrease in the amount of tin used throughout the 2nd millennium BCE despite the corresponding increase in tin-bronze frequency (Figure 53). However, the maximum values of tin content always remain above 14%, and when tin-bronze was at its most ubiquitous in the mid-2nd millennium BCE, the maximum value increases to almost 25%. The median and interquartile ranges remain low at this time, however, suggesting the presence of a few high tin bronzes in a generally low tin-bronze assemblage.

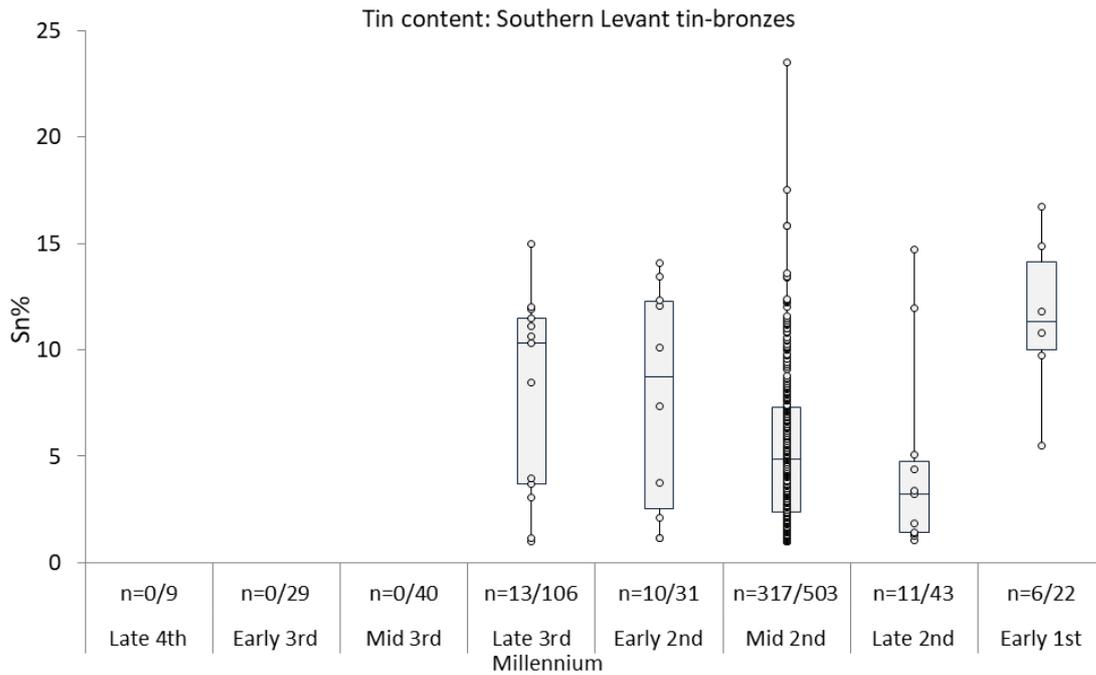


Figure 53: Box plot depicting tin content of all tin-bronzes (>1% Sn) from the Southern Levant

7.3 Copper groups

The pattern of copper group use in the Southern Levant from the early 3rd millennium BCE to the early 1st millennium BCE is also different from all neighbouring regions in Southwest Asia (Table 12), though it resembles most closely the signal from Cyprus. ‘Clean’ copper is the dominant group, accounting for 62% of the assemblage in the early 3rd millennium and 68% in the mid-3rd millennium, decreasing to 52% of the assemblage by the early 2nd millennium BCE. During this time arsenic-only copper increases at a rate of 5% of the assemblage every 300 years until it is the dominant copper group in the mid-2nd millennium after a slight dip in the previous period. In the early 1st millennium BCE arsenic-only and arsenic-nickel make up 27% of the assemblage together and ‘clean’ copper amounts to the remaining 73% of the assemblage. Though the Southern Levant was a region through which copious amounts of trade occurred, the

regional metallurgical tradition appears to indicate either isolation or a tightly controlled industry.

Table 12: Table depicting the entire Southern Levant copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi	Total
Late 4th	56%	33%	0%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	9
Early 3rd	62%	21%	0%	3%	3%	3%	0%	0%	7%	0%	0%	0%	0%	0%	0%	0%	29
Mid 3rd	68%	25%	0%	0%	0%	5%	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	40
Late 3rd	50%	33%	0%	2%	1%	9%	0%	0%	0%	0%	2%	0%	0%	1%	1%	1%	106
Early 2nd	52%	23%	0%	3%	13%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	31
Mid 2nd	44%	40%	1%	1%	1%	3%	0%	0%	4%	0%	4%	1%	0%	1%	1%	0%	503
Late 2nd	26%	49%	0%	5%	7%	5%	0%	0%	2%	0%	5%	2%	0%	0%	0%	0%	43
Early 1st	73%	18%	0%	0%	0%	0%	0%	0%	0%	0%	9%	0%	0%	0%	0%	0%	22

7.4 Arsenic, antimony, nickel, and silver content

The average arsenic content of all objects in the Southern Levant increases until the early 2nd millennium BCE, after which it begins to decrease until the early 1st millennium BCE (Figure 54). Copper ores in the region are generally not arsenic-rich, so the findings may indicate a period of increased import into the region, which is not visible in the copper group data. The average contents of antimony and nickel are always below 0.1%, but from the late 4th millennium to the early 2nd millennium BCE the patterns are very closely connected. Silver remains consistently low, with only a few objects' silver content rising above 0.1%.

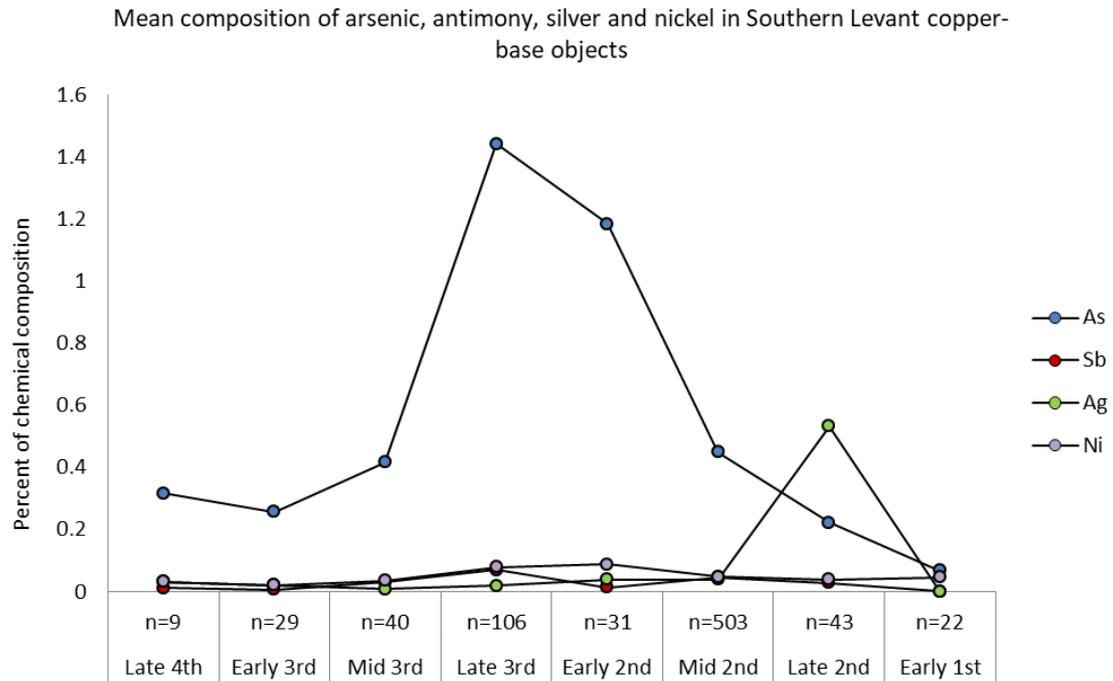


Figure 54: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from the Southern Levant

8 Northern Mesopotamia

8.1 Bronze ubiquity

Arsenical-bronze is the dominant alloy in use during the mid-3rd millennium BCE in Northern Mesopotamia, with all tin-bronzes (any >1% tin) making up roughly a quarter of the assemblage (Figure 55 and Figure 56). This picture is consistent into the late 3rd millennium BCE, though with a slight increase in the use of copper-arsenic-tin alloy and decrease in tin-bronze.

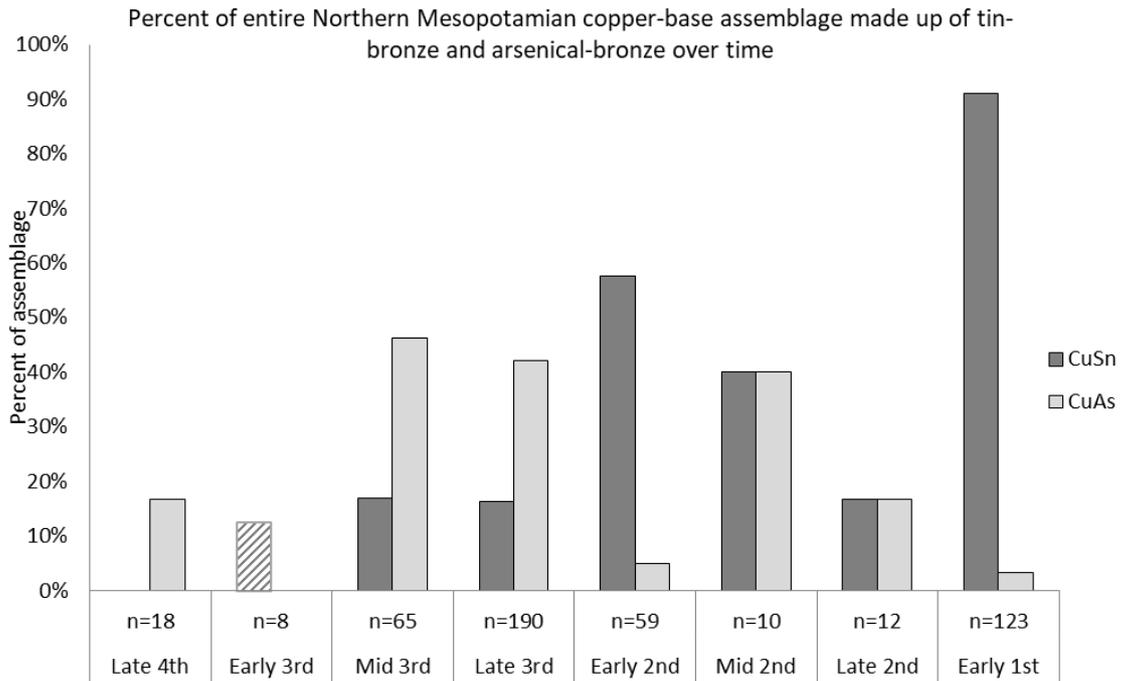


Figure 55: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in Northern Mesopotamia

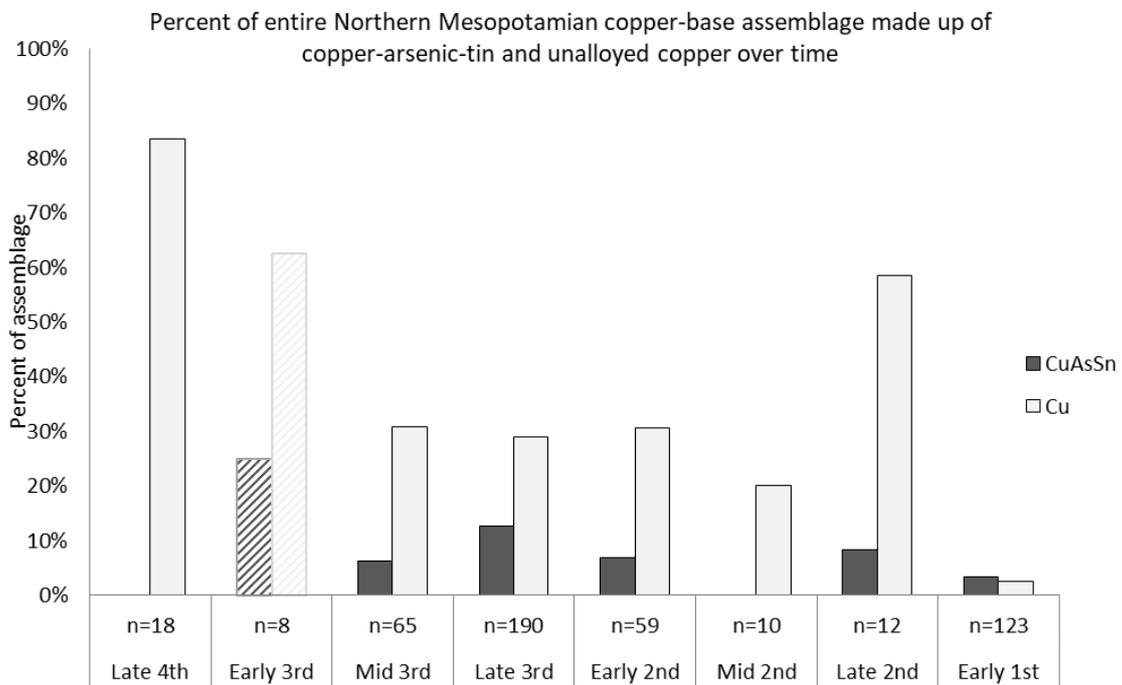


Figure 56: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in Northern Mesopotamia

The slight decrease in arsenical-bronze at this time (from 48% to 41% of the assemblage) is replaced by an increase in copper-arsenic-tin alloy (from 5% to 11% of the assemblage). In the early 2nd millennium BCE arsenical-bronze almost completely disappears and tin-bronze comprises 60% of the assemblage. Copper-arsenic-tin alloy decreased in use at the same time as arsenical-bronze did, suggesting an absence of arsenic alloying or a lack of access to arsenic-rich copper sources. In the early 1st millennium BCE almost the entire assemblage is made up of tin-bronze (91%).

8.2 Tin content

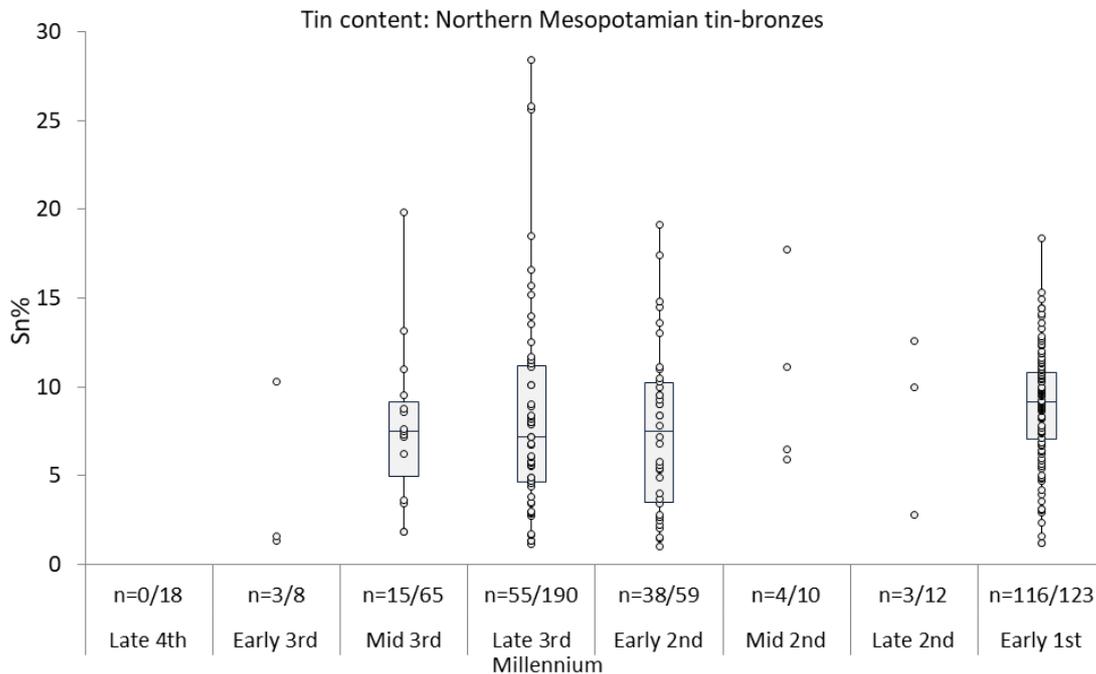


Figure 57: Box plot depicting tin content of all tin-bronzes (>1% Sn) from Northern Mesopotamia

There was a general increase in average tin content of all tin-bronze objects over the course of the 3rd millennium BCE in Northern Mesopotamia (Figure 57). The maximum tin content of all objects occurs in the late 3rd millennium, when three

objects (a pin from Mari and an axe-head and a figurine from Assur) contain 28.4%, 25.6% and 25.8% Sn. In the following period (early 2nd millennium BCE) the maximum tin content decreases to 19.1% Sn. During this period the interquartile range is large and encompasses much lower values, with the median tin content at 7% Sn and the minimum tin content just over 1% Sn. Half of the early 1st millennium assemblage contains objects with a tin content between 7% and 11% tin, with the median at 9% Sn. The maximum amount of tin content is averagely high at around 19%, and objects have tin content as low as 1% Sn. The pattern throughout the study period of objects containing as little as 1% Sn but varied and frequent objects containing >15% Sn might suggest consistent or easy access to tin, but also a simultaneous tradition of recycling.

8.3 *Copper Groups*

Apart from arsenic-only copper in the mid- and late 2nd millennium BCE, no copper group ever amounts to more than a third of the assemblage in Northern Mesopotamia (Table 13). There is less diversity in copper groups in the region than in neighbouring regions of Southwest Asia, but the number of objects in each group present is more substantial. Clean copper is only a major group in the late 2nd millennium BCE and early 1st millennium BCE, when it comprises between 17% and 25% of the assemblage. Arsenic-only copper is one of the major groups throughout almost the entire time period, apart from in the late 3rd millennium BCE, though it usually accounts for a quarter to a third of the assemblage. Arsenic-antimony makes up a quarter of the assemblage in the mid-3rd millennium and early 1st millennium BCE. Arsenic-nickel is present in quantities from 14% to 34%

of the assemblage until the early 1st millennium BCE, at which time it is no longer present in any significant quantity. Arsenic-antimony-nickel is more common in the 3rd millennium than later on. The changeability and variation of the copper group patterns in Northern Mesopotamia indicate communication and exchange with several different regions which varied significantly over time; this is could be due to its central position within Southwest Asia and positioning along the river-bound trade routes.

Table 13: Table depicting the entire Northern Mesopotamian copper-base assemblage split into copper groups as designated by the ‘Oxford technique’. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAg	AsSb	AsAg	AsSbAg	Total
Late 4th	6%	28%	0%	0%	6%	6%	0%	0%	6%	0%	17%	6%	0%	22%	0%	6%	18
Early 3rd	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%	63%	0%	0%	13%	0%	13%	8
Mid 3rd	6%	28%	0%	0%	2%	20%	0%	0%	0%	0%	14%	8%	0%	15%	6%	2%	65
Late 3rd	6%	4%	0%	0%	1%	4%	0%	0%	1%	0%	34%	1%	0%	34%	8%	8%	190
Early 2nd	15%	22%	0%	0%	5%	0%	0%	0%	5%	0%	31%	7%	0%	3%	10%	2%	59
Mid 2nd	0%	40%	0%	0%	0%	0%	0%	0%	0%	0%	30%	10%	0%	10%	10%	0%	10
Late 2nd	17%	50%	0%	0%	0%	8%	0%	0%	0%	0%	25%	0%	0%	0%	0%	0%	12
Early 1st	24%	32%	0%	2%	2%	25%	0%	0%	0%	0%	2%	10%	0%	2%	0%	0%	123

8.4 Arsenic, antimony, nickel, and silver content

The instability and variation in Northern Mesopotamian metallurgical tradition is also visible in the mean contents of arsenic, antimony, silver, and nickel (Figure 58). After an increase in average arsenic-content from the early 3rd to the mid-3rd millennium BCE, there is a small period of stability as the average remains at a similar level into the late 3rd millennium BCE. Moving into the 2nd millennium, however, there is a substantial change in arsenic content. The average contents of antimony, silver, and nickel are also very variable between time periods, though silver and antimony contents decrease at a similar pace from the late 3rd millennium to the late 2nd millennium BCE. The fluctuation of average contents of

both arsenic and antimony appear to show some similarities over time, also reflecting the changes in ubiquity of arsenic-nickel. Again, this would appear to represent the central position of the region along trade routes.

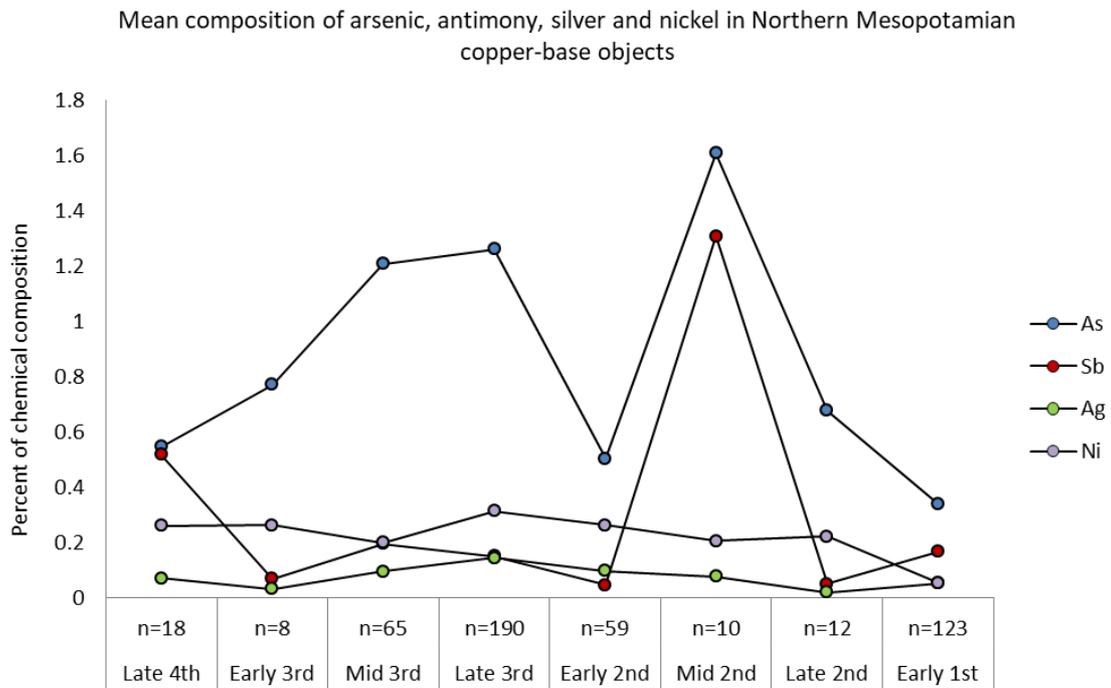


Figure 58: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from Northern Mesopotamia

9 Mesopotamia

9.1 Bronze ubiquity

From the early 3rd millennium BCE to the early 2nd millennium BCE tin-bronze use in Mesopotamia increased from 5% of the assemblage to 38%, at this same time arsenical-bronze decreased from 62% of the assemblage to 11% (Figure 59) displaying a similar, if smaller scale, pattern to the Southern Caucasus. It is only in the early 2nd millennium BCE that tin-bronze became the dominant alloy, though it only accounts for 3% more of the assemblage than unalloyed copper (Figure 60). It

is worth bearing in mind that though the percentage of the assemblage made up of tin-bronze in the late 3rd millennium BCE appears low in comparison to neighbouring regions, the actual quantity of tin required to produce the large number of tin-bronzes is larger than in any other period or region, as there are nearly 600 tin-bronze objects present in the assemblage.

Copper-arsenic-tin use increased steadily throughout the 3rd millennium and early 2nd millennium BCE as well. The fact that arsenical-copper use declines at the same time, and unalloyed copper remains stable, this might suggest the addition of tin to arsenic-rich copper rather than addition of tin to unalloyed copper. From the mid-2nd millennium to the early 1st millennium BCE there is only unalloyed copper and tin-bronze present, but the assemblages comprise less than ten artefacts so are only represented with hatched lines. If they are representative of the metallurgical industry as a whole during these periods then tin-bronze from this point amounts to either almost half or more than half of the overall assemblage.

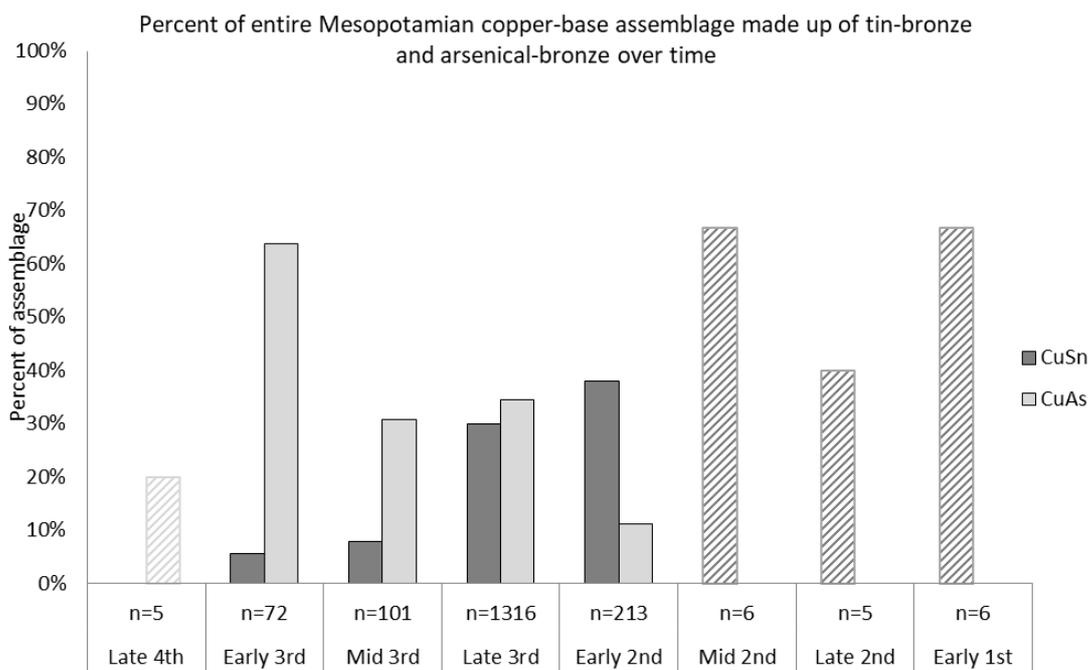


Figure 59: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in Mesopotamia

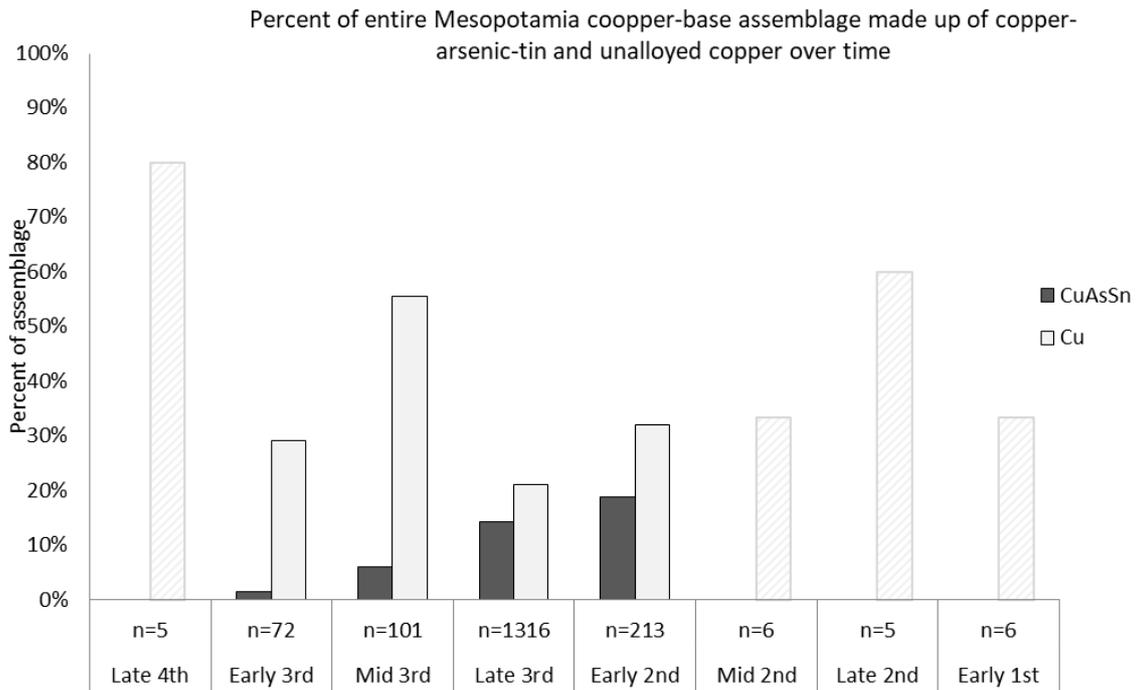


Figure 60: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in Mesopotamia

9.2 Tin content

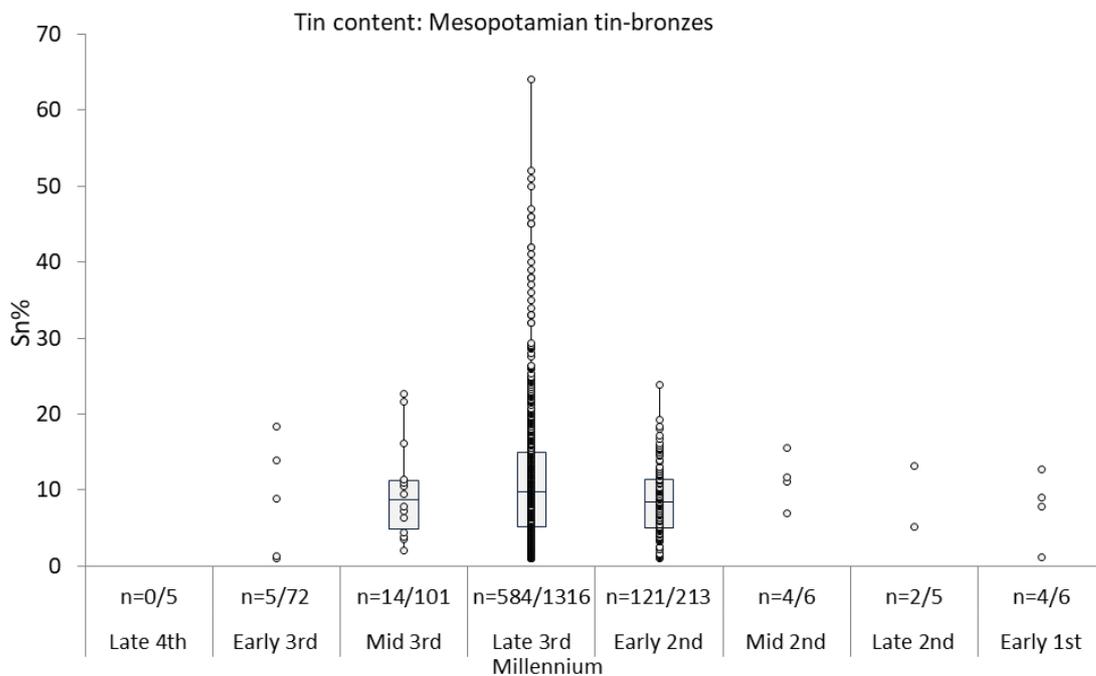


Figure 61: Box plot depicting tin content of all tin-bronzes (>1% Sn) from Mesopotamia

In the early 3rd millennium BCE the 5 objects containing tin (copper-arsenic-tin alloy and tin-bronze together) that make up 7% of the entire assemblage have quite a wide range of values (Figure 61). Two objects contain around 1% tin, but the other three are higher tin bronzes (8.9%, 13.9% and 18.3%). The copper-arsenic-tin object is one of the objects with around 1% tin, which could suggest mixed or recycled material. All objects, except the highest tin bronze, have arsenic present in amounts between 0.4% and 0.8%. In the late 3rd millennium BCE, a quarter of the assemblage contains between 10% and 15% tin and the maximum value of tin content is 64% which is unusually high (there are twenty-six objects with >30%, suggesting that it is not simply an anomaly: for further discussion see the section on Eastern Arabian tin content).

9.3 Copper Groups

Table 14: Table depicting the entire Mesopotamian copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAg	AsSb	AsAg	AsSbAg	Total
Late 4th	0%	20%	0%	0%	0%	0%	0%	0%	0%	0%	40%	0%	0%	20%	0%	20%	5
Early 3rd	3%	40%	0%	3%	0%	4%	0%	0%	13%	0%	14%	6%	0%	8%	4%	6%	72
Mid 3rd	10%	40%	1%	3%	1%	4%	1%	0%	5%	0%	18%	5%	0%	5%	3%	5%	101
Late 3rd	3%	11%	0%	1%	2%	3%	0%	0%	4%	0%	34%	1%	0%	21%	11%	9%	1316
Early 2nd	2%	16%	0%	0%	1%	4%	0%	0%	6%	0%	49%	1%	0%	5%	14%	1%	213
Mid 2nd	17%	17%	0%	0%	0%	0%	0%	0%	0%	0%	33%	0%	0%	17%	17%	0%	6
Late 2nd	20%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5
Early 1st	17%	50%	0%	0%	0%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	17%	6

The main copper compositions in use in Mesopotamia from the early 3rd millennium to the early 2nd millennium BCE were arsenic-only and arsenic-nickel (Table 14). Other groups were also present in significant amounts at varying times, such as arsenic-silver, arsenic-antimony-nickel and arsenic-silver-nickel. In the

early 3rd millennium BCE arsenic-only copper made up around 40% of the overall assemblage, this decreases throughout the 3rd millennium. Arsenic-nickel copper on the other hand increases from 13% of the assemblage to just below 50% in the early 2nd millennium BCE, effectively replacing the arsenic-only copper. The number of different copper groups in use at one time increases from ten in the early 3rd millennium to fourteen at the end of the millennium, but the diversity decreases once more at the beginning of the next millennium, though after the early 2nd millennium BCE this is more due to a limitation in object numbers. The variation in copper composition is consistent with a region lacking its own resources and dependent on those of its numerous trading partners.

9.4 Arsenic, antimony, nickel, and silver content

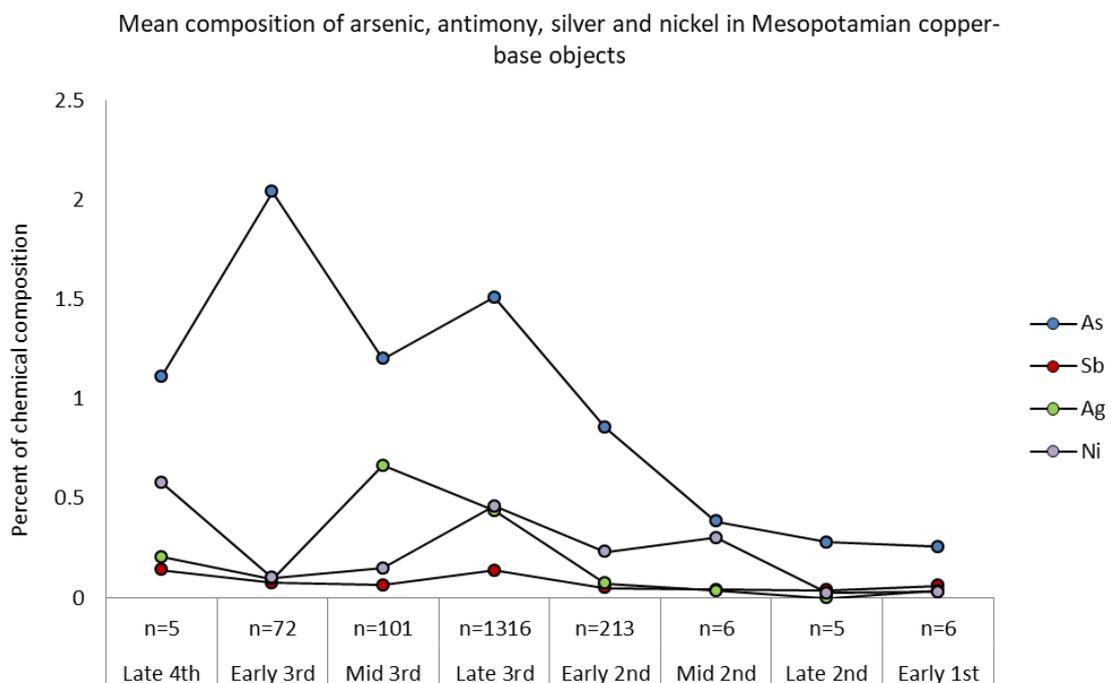


Figure 62: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from Mesopotamia

As the two dominant copper groups present in Mesopotamia throughout the Bronze Age contain arsenic it is not altogether surprising that over 75% of all the assemblages contain more than 0.1% arsenic (Figure 62). What does appear to be somewhat unusual are the very high values of arsenic in the early, mid and late 3rd millennium BCE (maximum values are respectively 12.3%, 17.9% and 16.2% As). Though the maximum arsenic content in the mid-3rd millennium BCE is as high as 17.9% the mean arsenic content decreases at this time suggesting lower arsenic contents to be more frequent.

The average (mean) antimony, silver and nickel contents of all objects show more variation in the Mesopotamian assemblages than in any other region of Southwest Asia discussed so far. The peak in average silver content in the mid-3rd millennium BCE is interesting, as silver does not tend to be present in significant amounts in most objects from Southwest Asia.

10 Luristan

10.1 Bronze ubiquity

In a similar pattern to the bronze traditions of Mesopotamia and the Southern Caucasus, there was a decrease in arsenical-bronze use with a simultaneous increase in tin-bronze use over time in Luristan (Figure 63). Arsenical-bronze continues to account for 22% of the assemblage until the mid-2nd millennium BCE, after which it mostly disappears.

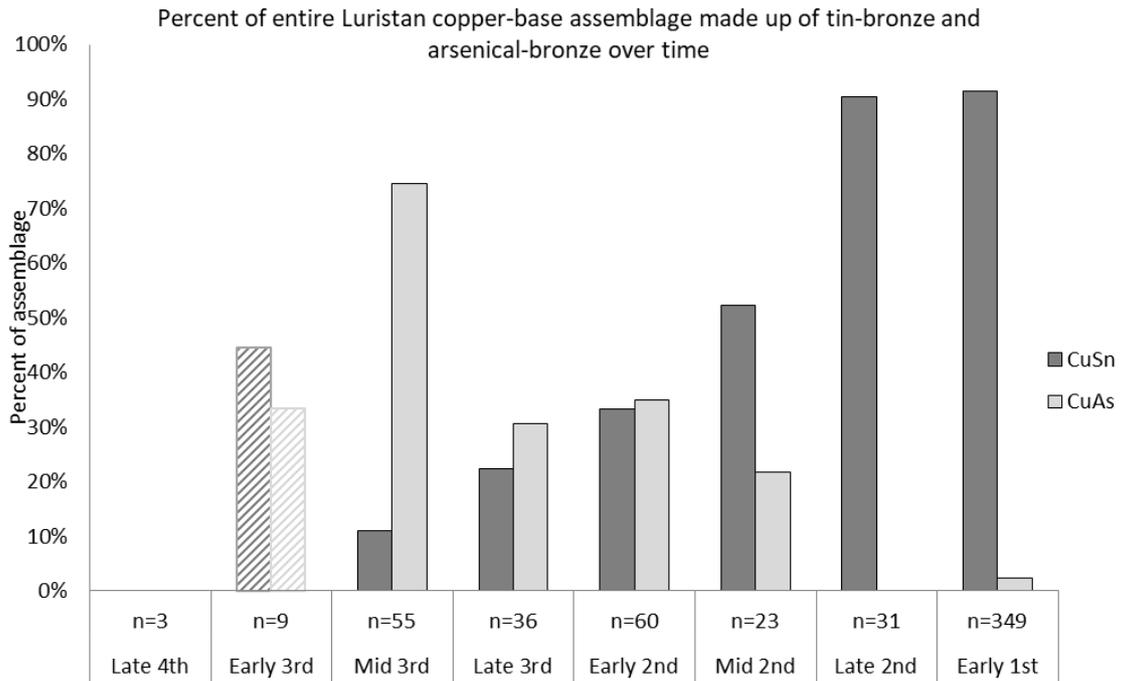


Figure 63: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in Luristan

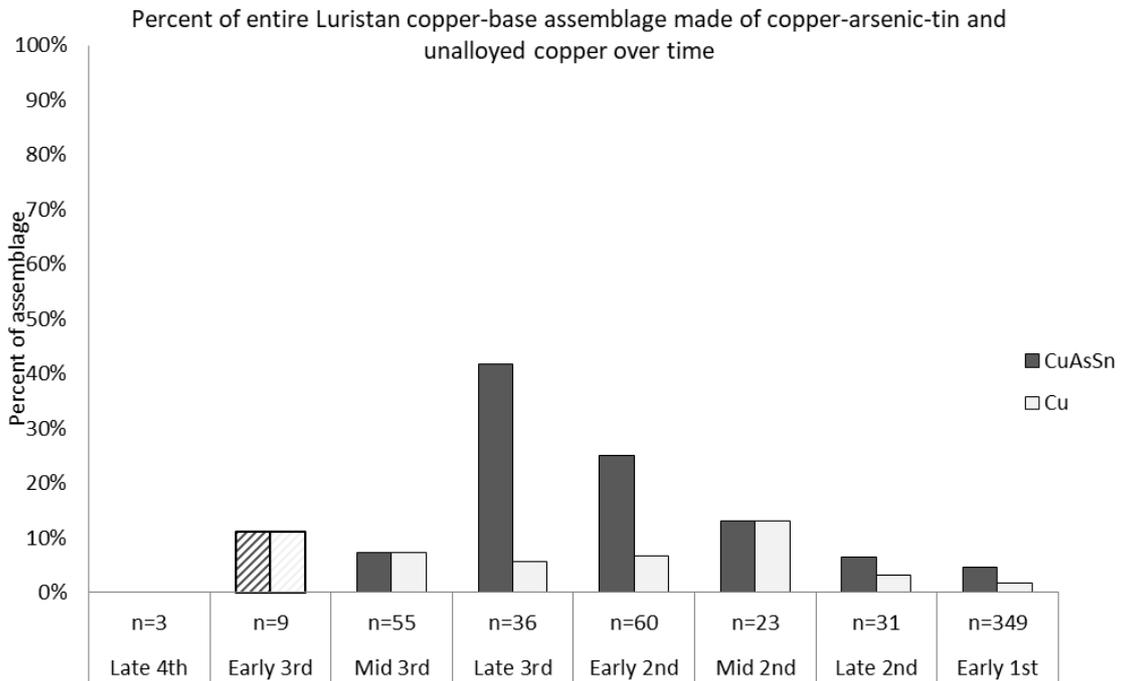


Figure 64: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in Luristan

The use of unalloyed copper in Luristan was unusually and consistently minimal, never amounting to more than 15% of the assemblage (Figure 64). Copper-

arsenic-tin also displays an unusual pattern of being the dominant alloy in the late 3rd millennium BCE, before steadily decreasing in use until the early 1st millennium BCE. The tradition of tin-bronze-metallurgy seems to have been well developed from an early period of time in Luristan.

10.2 Tin content

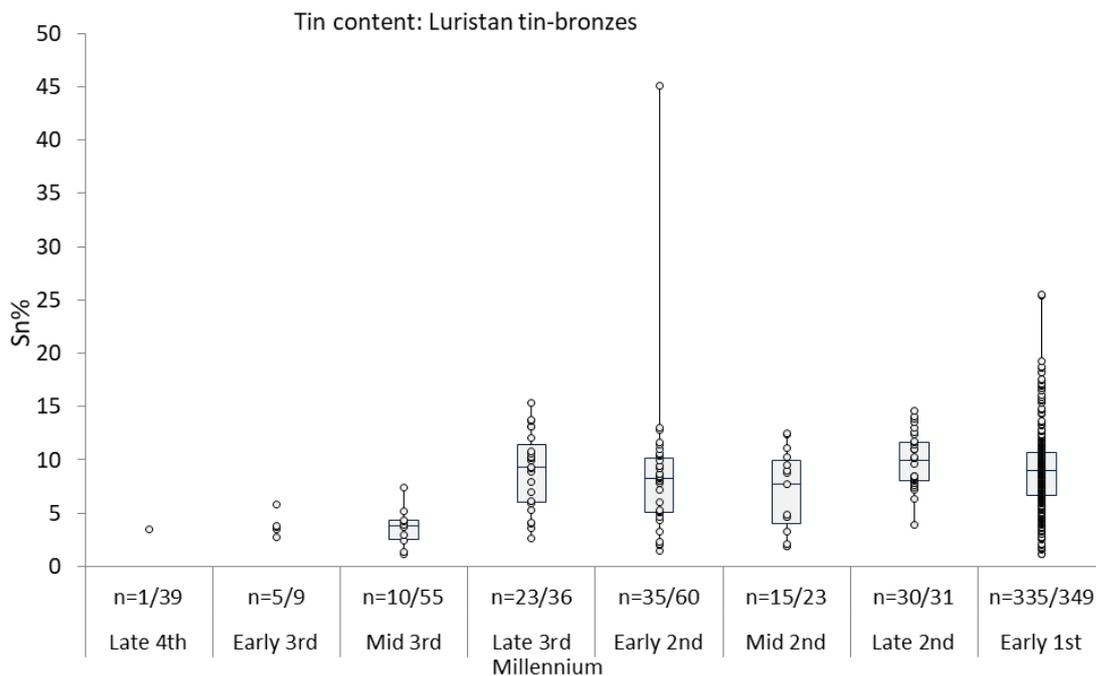


Figure 65: Box plot depicting tin content of all tin-bronzes (>1% Sn) from Luristan

Though Luristan tin-bronzes occur from an early date, the tin content of all tin-bronze objects remains low (median tin content between 3% and 4% Sn) and there was little variation in ranges of tin composition until the mid-3rd millennium BCE (Figure 65). In the late 3rd millennium BCE the median tin content jumps from 4% Sn to 9% Sn, though this decreases again to around 8% Sn in the early and mid-2nd millennium BCE. In the early 2nd millennium one object contains just over 46% Sn, but this is an anomaly, with 13% being the next highest maximum tin content in an object. With that in mind the transition to the mid-2nd millennium BCE tin-

bronze use displays consistency in tradition, though the interquartile range is slightly larger (with half of the objects containing between 4% and 10% Sn, rather than 5% to 11% Sn as in the earlier period). In the late 2nd millennium the median, lower quartile, upper quartile, minimum and maximum values all increase, though the interquartile range narrows suggesting a form of stability in production, but with a large number of irregular tin-bronzes. In the early 1st millennium BCE the median decreases to 9%, but the maximum amount of tin rises from 15% to 25% Sn, and the minimum decreases from 4% to 1% Sn, revealing the presence more low-tin objects.

10.3 Copper Groups

Table 15: Table depicting the entire Luristan copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi	Total
Late 4th	0%	0%	0%	0%	33%	0%	0%	0%	0%	0%	33%	0%	0%	33%	0%	0%	3
Early 3rd	0%	11%	0%	0%	11%	0%	0%	0%	0%	0%	56%	0%	0%	22%	0%	0%	9
Mid 3rd	0%	13%	0%	4%	0%	7%	0%	0%	16%	2%	16%	5%	0%	13%	15%	9%	55
Late 3rd	0%	17%	0%	0%	3%	6%	0%	0%	8%	0%	25%	0%	0%	8%	28%	6%	36
Early 2nd	2%	20%	2%	2%	3%	5%	0%	2%	5%	2%	32%	2%	0%	5%	20%	0%	60
Mid 2nd	17%	26%	0%	0%	0%	13%	0%	0%	0%	0%	26%	0%	0%	0%	13%	4%	23
Late 2nd	13%	55%	3%	0%	0%	3%	0%	3%	6%	0%	10%	0%	0%	0%	6%	0%	31
Early 1st	17%	30%	1%	6%	5%	6%	1%	1%	5%	0%	16%	2%	0%	3%	4%	4%	349

The pattern of copper group use was almost as varied in Luristan as in Northern Mesopotamia (Table 15). Apart from in the late 2nd millennium BCE when arsenic-only copper amounts to more than half, no group represents more than a third of the assemblage at any time. Unlike in the Northern Mesopotamian assemblages, arsenic-only and arsenic-nickel are more consistently in use over time. There is also an increase in the use of clean copper towards the end of the 2nd millennium BCE and beginning of the 1st millennium BCE. The use of arsenic-nickel copper

varies from one quarter to almost one third of the entire assemblage until the mid-2nd millennium. Arsenic-silver-nickel is also quite consistently common until the early 2nd millennium BCE. The diversity of copper groups varies substantially over time, with peaks in diversity in the early 2nd millennium and early 1st millennium BCE.

10.4 Arsenic, antimony, nickel, and silver content

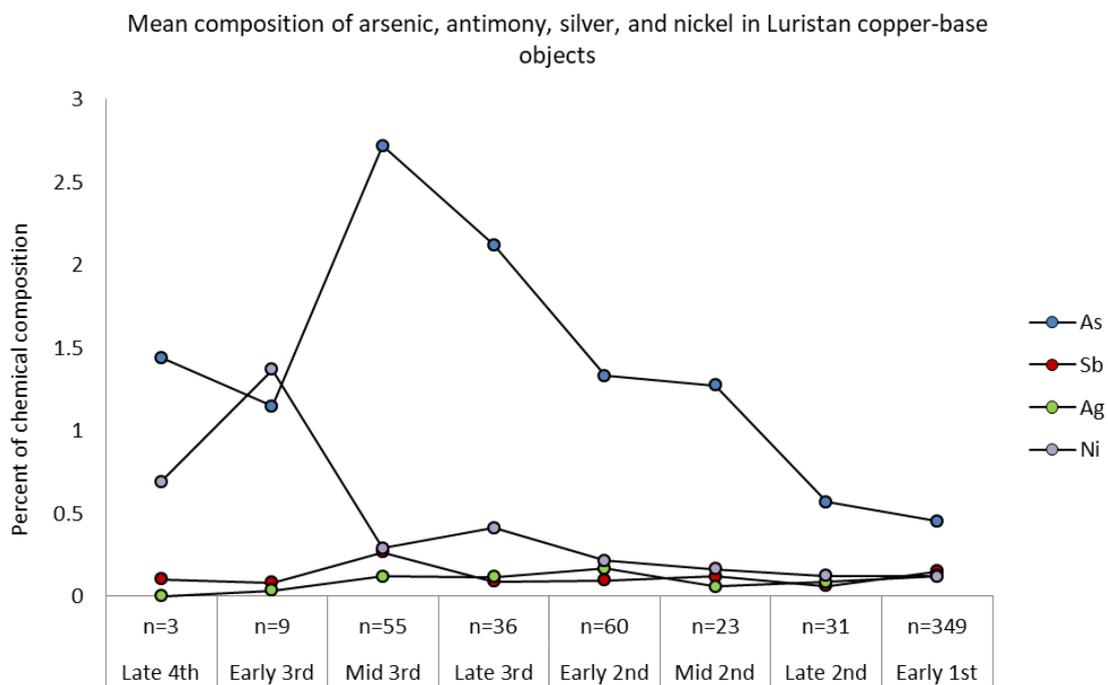


Figure 66: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from Luristan

The mean averages of arsenic, antimony, nickel and silver (Figure 66), show that the average arsenic content rises until the mid-3rd millennium BCE, and then decreases slowly over time. The average nickel content in the early 3rd millennium BCE is actually slightly higher than the average arsenic content, but as the arsenic content rises in the next period, there is a sharp contemporaneous decrease in

average nickel content –these trace elements do not appear to be coming from the same source in the mid-3rd millennium BCE. Average concentrations of antimony, nickel and silver all increase slightly in the early 1st millennium BCE.

11 Western Elam

11.1 Bronze ubiquity

Arsenical-bronze is the dominant alloy in use during the 4th millennium BCE in Western Elam, comprising 80% of the assemblage (Figure 67). This figure decreases by around 5% in the following period, and by another 15% into the mid-3rd millennium BCE. A very small amount of tin-bronze is in use in the late 4th millennium, but this disappears in the early 3rd millennium BCE. In the late 3rd millennium BCE arsenical-bronze use reduces drastically from 61% of the assemblage to 22%, it is mainly replaced by unalloyed copper (Figure 68), though the amount of tin-bronze and copper-arsenic-tin alloy increases slightly indicating a small but not significant influx of tin to the region towards the end of the millennium. Throughout the 2nd millennium the use of tin-bronze increases slightly, but unalloyed copper appears to be the copper-type of choice, finally amounting to nearly 80% of the assemblage.

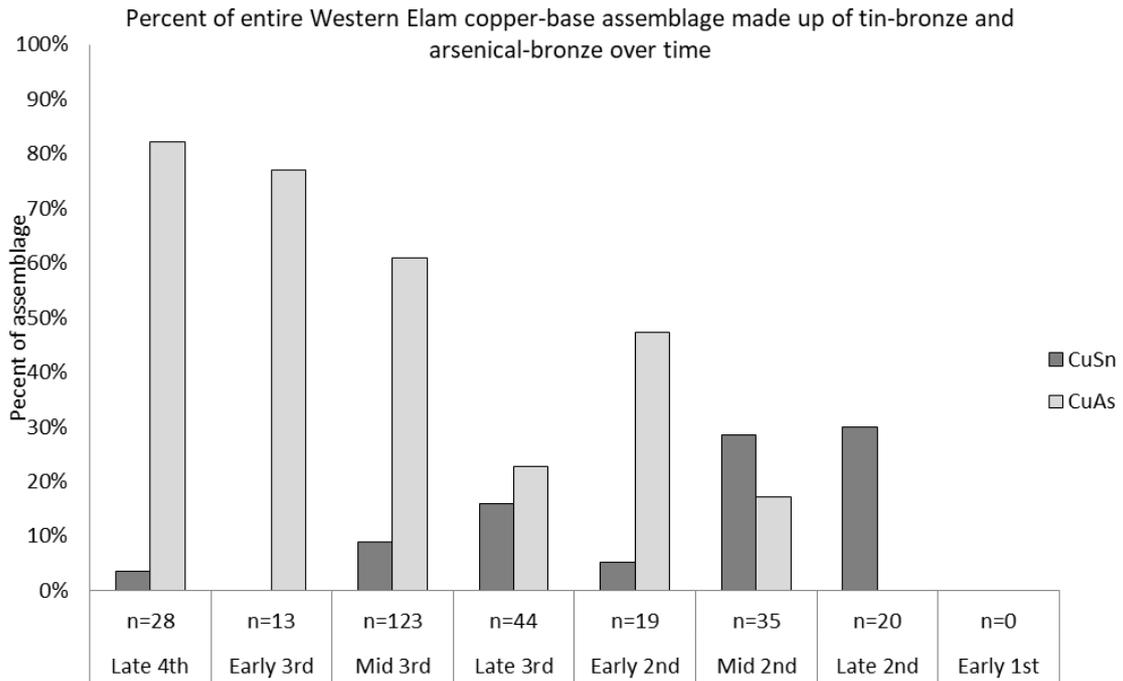


Figure 67: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in Western Elam

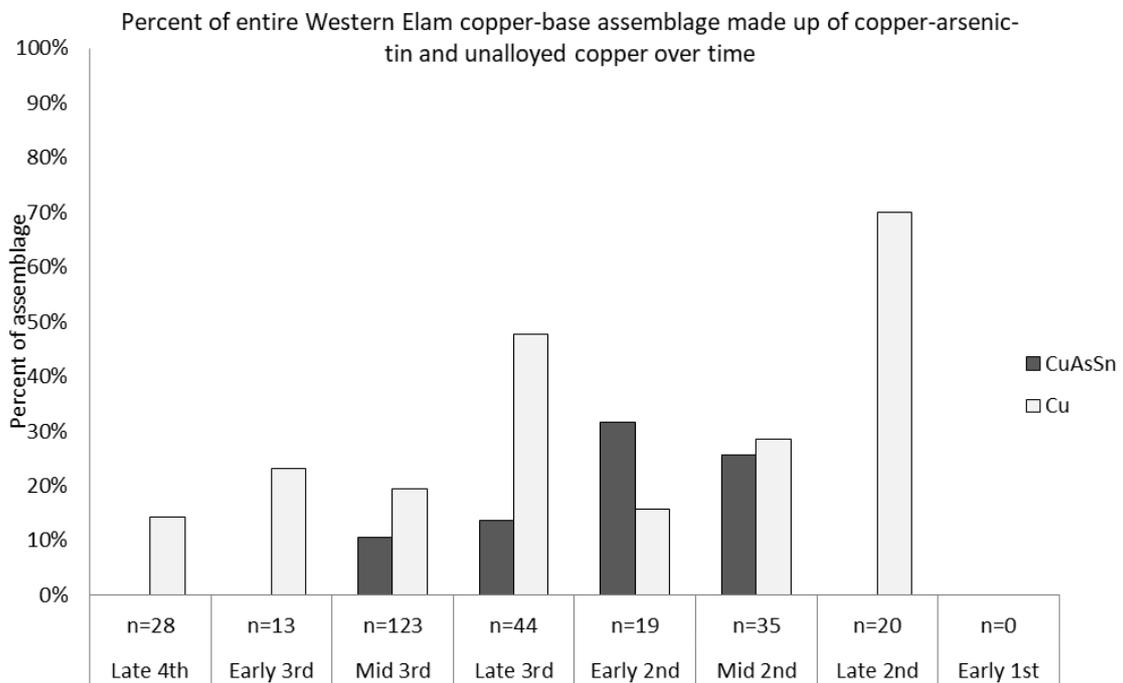


Figure 68: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in Western Elam

11.2 Tin content

The median tin content of the mid-3rd millennium BCE tin-bronzes is around 6%, but this decreases to 5% by the early 2nd millennium (Figure 69). The maximum value of tin decreases from above 20% in the mid-3rd millennium (a mid-3rd millennium mace-head from Susa) to 11.2% in the early 2nd millennium (one of two axe-heads from Elam containing ~11% Sn). In the mid-2nd millennium the range of tin composition is very similar to that of the preceding period, but the median has increased to just above 6%. The picture is that of a consistently low-tin bronze tradition with the occasional appearance of a high-tin object, perhaps coming from outside the region.

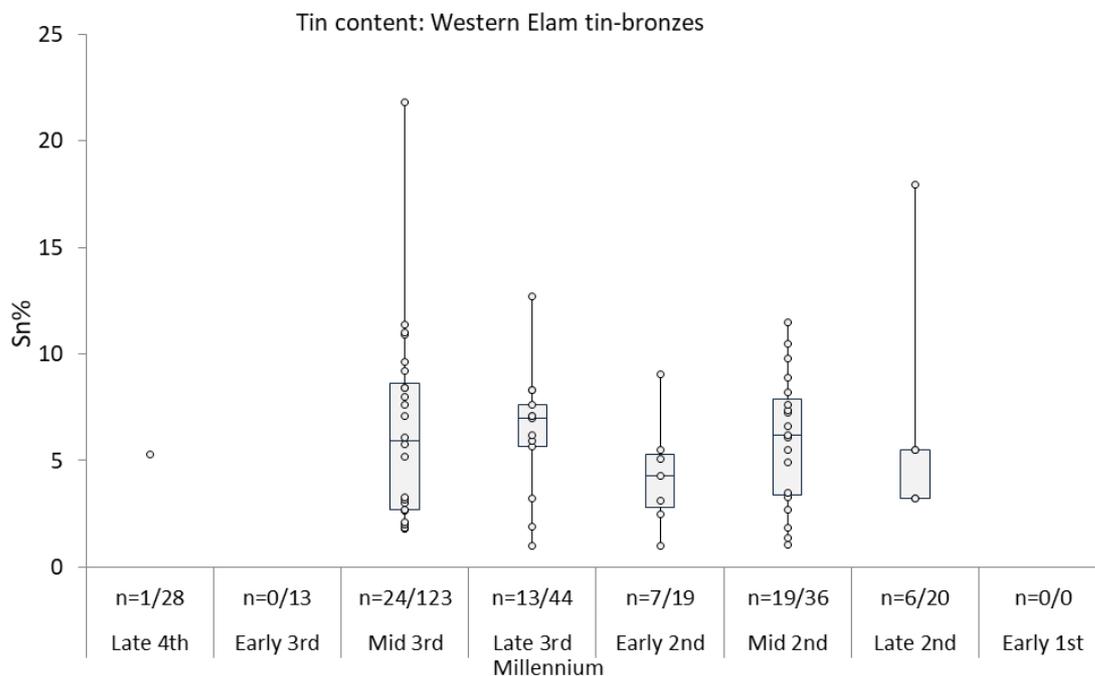


Figure 69: Box plot depicting tin content of all tin-bronzes (>1% Sn) from Western Elam

11.3 Copper Groups

The copper groups present in Western Elam display a completely different metallurgical tradition from the regions in Southwest Asia discussed so far (Table 16). Arsenic-nickel copper is consistently present as a major group increasing to 52% of the assemblage until the late 2nd millennium BCE when it disappears entirely. Arsenic-antimony-nickel use peaks in the early 2nd millennium BCE (comprising 58% of the assemblage), before dropping to only 6% and eventually disappearing. Copper made with arsenic-silver-nickel is more abundant in this region than elsewhere. The entire copper group signal changes in the late 2nd millennium BCE, which could indicate a change in tradition or source of material but should be treated with caution due to the limited number of objects in the assemblage. Interestingly, the three groups present during this time period have not occurred at any point previously in the region. The diversity of copper groups is also more restricted than in neighbouring regions, with only 8 of the 16 copper groups ever present.

Table 16: Table depicting the entire Western Elam copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAg	AsSb	AsAg	AsSbAg	Total
Late 4th	4%	0%	0%	0%	0%	4%	0%	0%	7%	0%	21%	7%	0%	25%	11%	21%	28
Early 3rd	0%	15%	0%	0%	0%	0%	0%	0%	0%	0%	38%	8%	0%	15%	23%	0%	13
Mid 3rd	0%	11%	0%	0%	0%	2%	0%	0%	4%	0%	43%	0%	0%	24%	9%	8%	123
Late 3rd	0%	7%	0%	0%	0%	0%	0%	0%	0%	0%	14%	0%	0%	30%	43%	7%	44
Early 2nd	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	32%	11%	0%	58%	0%	0%	19
Mid 2nd	6%	11%	0%	3%	3%	0%	0%	0%	0%	0%	51%	0%	0%	6%	14%	6%	35
Late 2nd	0%	0%	0%	0%	20%	0%	0%	20%	0%	0%	0%	0%	60%	0%	0%	0%	20
Early 1st																	

11.4 Arsenic, antimony, nickel, and silver content

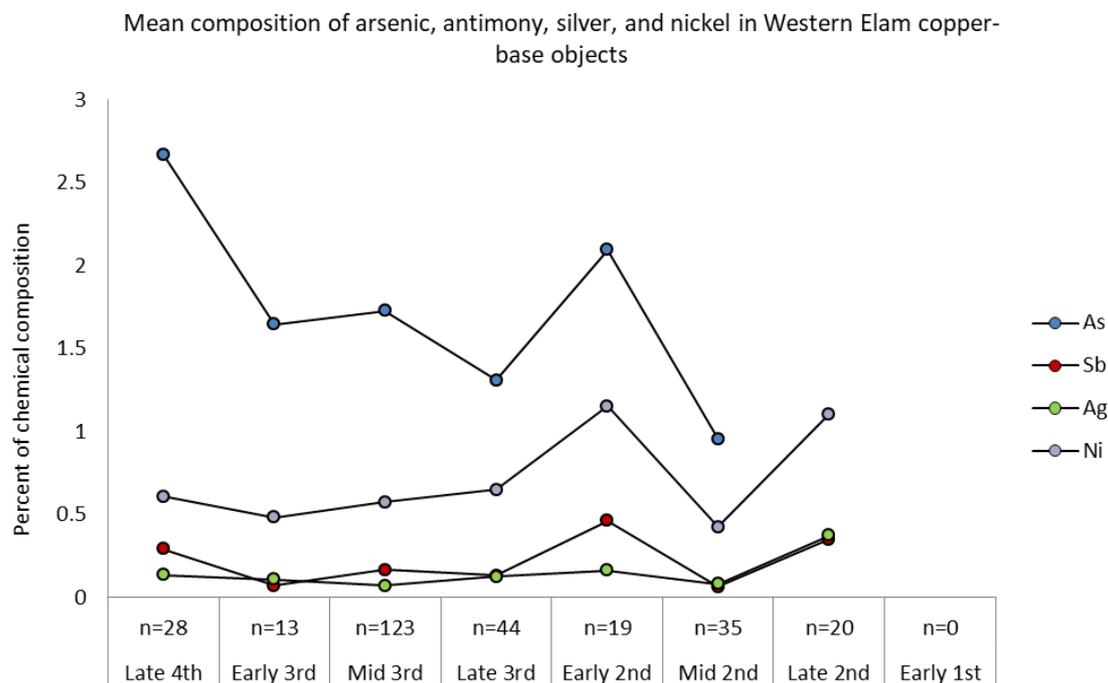


Figure 70: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from Western Elam

There is a distinct loss of average arsenic over time in Western Elam, but a fairly steady mean nickel average (Figure 70). Nickel content increases gradually from the early 3rd millennium BCE to the early 2nd millennium (0.6% - 1.05% Ni). From the late 3rd millennium to early 2nd millennium average arsenic, antimony and nickel contents increase simultaneously, which may indicate a link between these trace elements or perhaps a change in smelting technique. When arsenic disappears from the record there is an increase in antimony, silver, and nickel contents, perhaps indicating an influx of copper from a specific alternate region, such as the Caucasus.

12 Caspian Sea Coast (Iran)

12.1 Bronze ubiquity

The patterns of tin-bronze and arsenical-bronze use on the Iranian coast of the Caspian Sea show a sharp divide in time (Figure 71). When arsenical-bronze is present, tin-bronze is almost entirely absent and vice versa. Even copper-arsenic-tin alloys are absent when arsenical-bronze is the dominant alloy (Figure 72). Copper-arsenic-tin is only minimally present from the mid-2nd millennium BCE onwards, when tin-bronze makes up over 60% of the assemblage. Arsenical-bronze is almost completely replaced by tin-bronze from the mid-2nd millennium BCE onwards, indicating a major change in the region. Unalloyed copper is habitually present but steadily decreases over time.

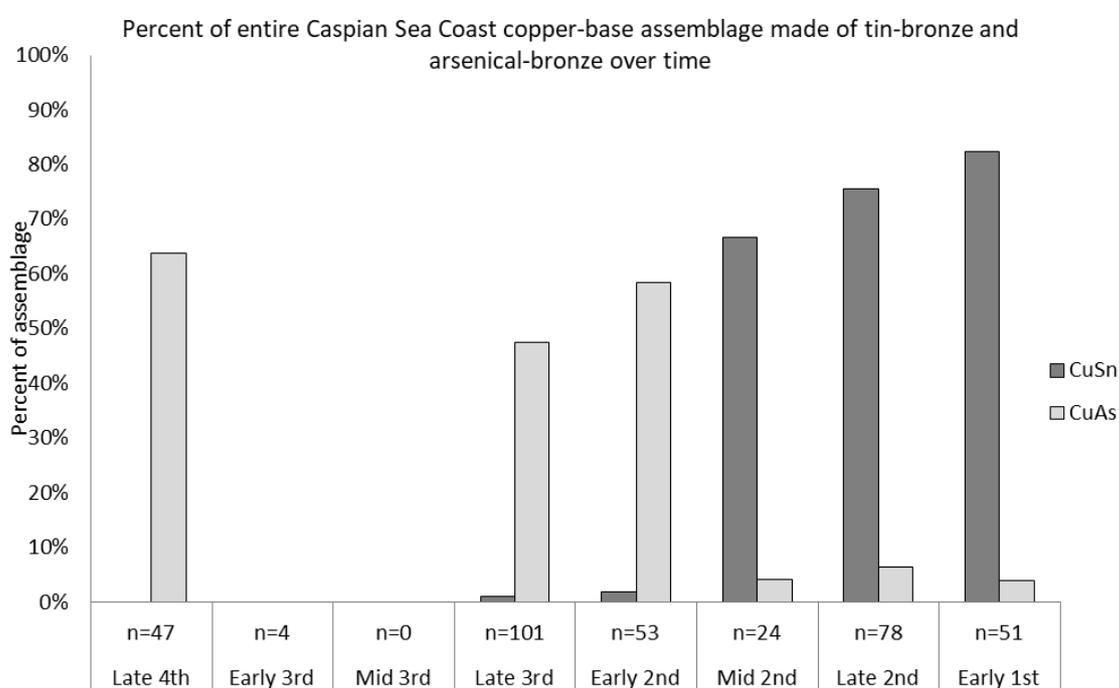


Figure 71: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) on the Iranian Coast of the Caspian Sea

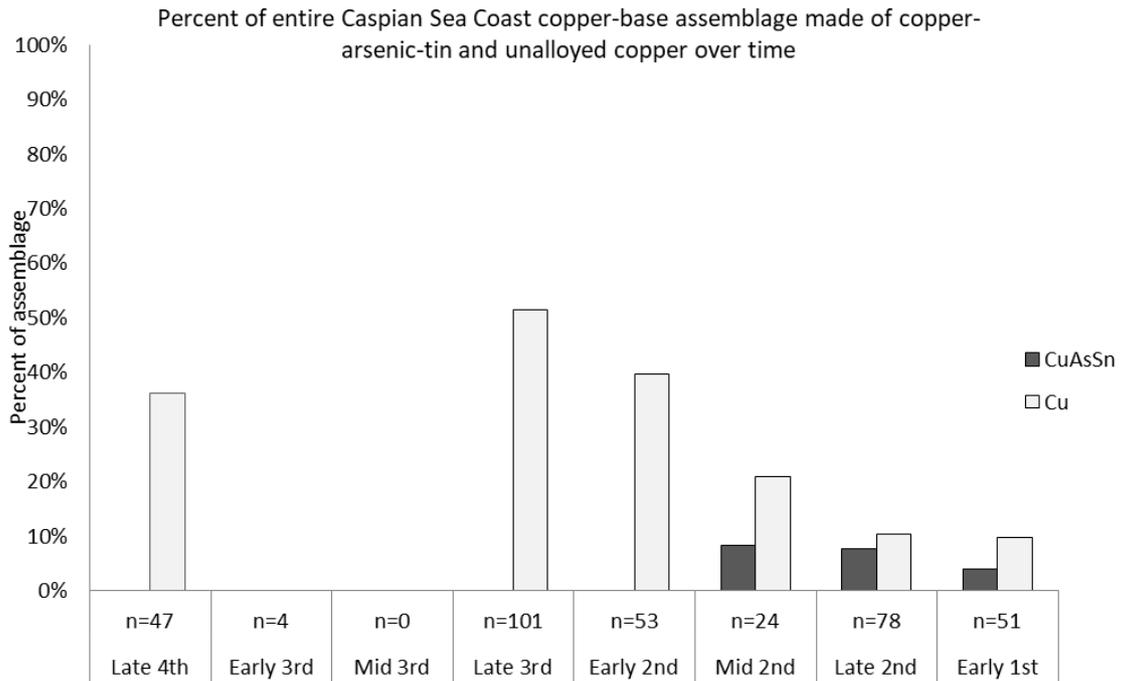


Figure 72: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) on the Iranian Coast of the Caspian Sea

12.2 Tin content

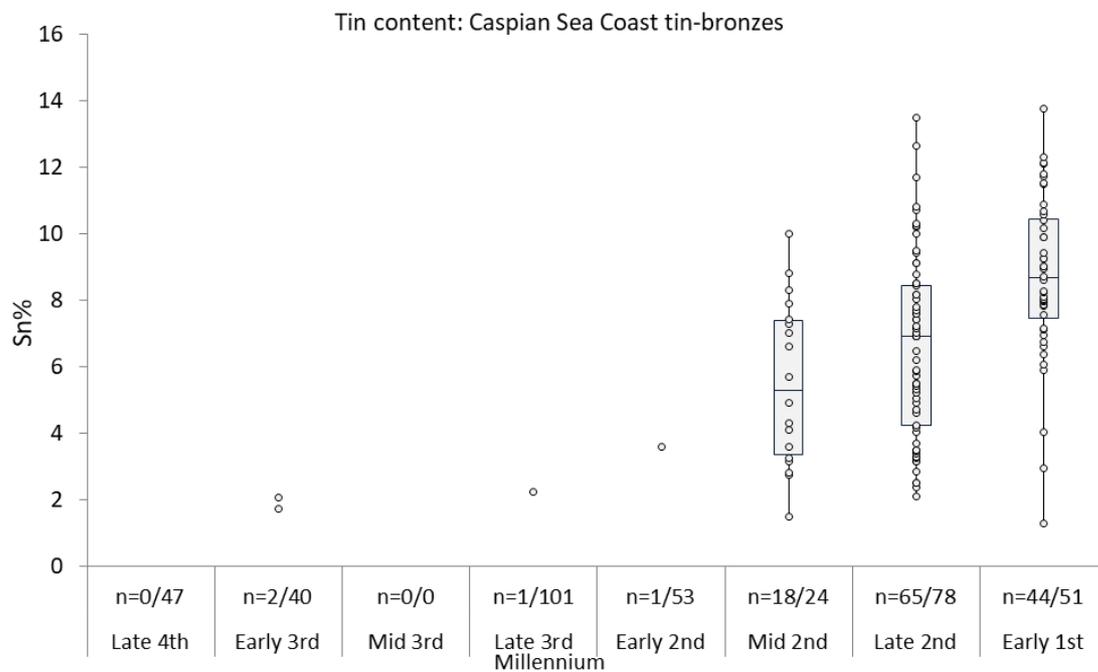


Figure 73: Box plot depicting tin content of all tin-bronzes (>1% Sn) from the Iranian Coast of the Caspian Sea

Given the scarcity of tin-bronzes in the Caspian Sea Coastal region until the mid-3rd millennium BCE, the low level of tin content shown from the solitary objects from the late 3rd millennium and early 2nd millennium BCE in Figure 73 is to be expected. From the mid-2nd millennium to the early 1st millennium BCE the median tin content in the tin-bronzes increases from 5% Sn to 9% Sn, with the maximum tin content value rising as well. The overall range of tin content also increases in the early 1st millennium; spanning 1% Sn to 14% Sn, though three quarters of the tin-bronze objects contain more than 7% Sn. Even with plenty of tin-bronze in the region, the actual composition of objects does not indicate much experimentation or variation with tin-bronze use, nor regional access to large amounts of tin; it is possible that tin-bronze objects were imported in, rather than the region having its own tin-bronze industry. This is also indicated by the suddenness with which tin-bronze became ubiquitous.

12.3 Copper Groups

The three dominant copper compositions in the Caspian Sea Coastal region in Iran rarely represent more than a third of the overall assemblage, apart from arsenic-only copper, which accounts for 60% of the assemblage in the late 4th millennium and 45% of the assemblage in the early 2nd millennium BCE (Table 17). Apart from these two instances, arsenic-only copper is the most consistently ubiquitous copper group in the region, always being present at around 30% of the assemblage. 'Clean' copper becomes a dominant group from the mid-2nd millennium BCE onwards, and arsenic-silver fluctuates between being a major and dominant group. The silver-only copper group is always present in this region to

some degree but is more prevalent in the mid- and late 3rd millennium BCE. The diversity of copper groups remains mostly stable over time.

Table 17: Table depicting the entire Caspian Coast copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi	Total
Late 4th	2%	60%	0%	4%	4%	6%	0%	0%	6%	0%	4%	9%	0%	0%	4%	0%	47
Early 3rd	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4
Mid 3rd																	
Late 3rd	14%	32%	0%	4%	0%	7%	0%	0%	30%	1%	2%	7%	0%	0%	0%	4%	101
Early 2nd	8%	45%	0%	4%	2%	4%	0%	0%	13%	0%	15%	0%	0%	2%	6%	2%	53
Mid 2nd	29%	29%	0%	17%	0%	0%	0%	0%	21%	0%	0%	4%	0%	0%	0%	0%	24
Late 2nd	24%	29%	4%	10%	0%	5%	1%	0%	23%	0%	0%	3%	0%	0%	0%	0%	78
Early 1st	33%	31%	0%	6%	4%	8%	0%	0%	10%	0%	0%	4%	0%	0%	0%	4%	51

12.4 Arsenic, antimony, nickel, and silver content

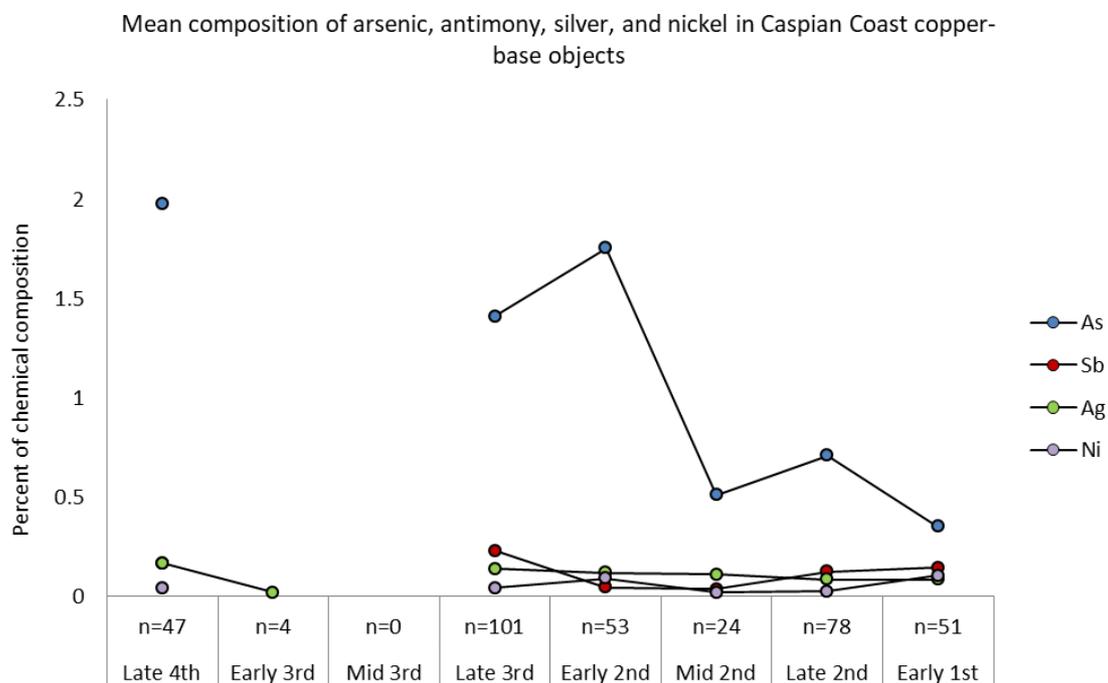


Figure 74: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from the Iranian Coast of the Caspian Sea

The average content of arsenic, antimony, nickel and silver in all objects from the Caspian Sea Coast are represented in Figure 74. There is an overall decline in the amount of arsenic present in the assemblages, though the maximum amount of arsenic found is mostly somewhat high (around 5% As). From the early 2nd millennium to the mid-2nd millennium BCE there is a sharp decline in arsenic content, suggesting some form of abrupt change in the mid-2nd millennium. Antimony, silver and nickel remain quite low, but occasionally the mean average is above 0.1%.

13 Kerman

13.1 Bronze ubiquity

Tin-bronze of any kind is almost entirely absent from Kerman from the late 4th millennium BCE to the mid-2nd millennium BC (Figure 75); there is one tin-bronze object dating to the mid-3rd millennium and six (three tin-bronze, three copper-arsenic-tin alloys all of which are dress objects) dating to the mid-2nd millennium BCE. There does not appear to have been a tradition of tin-bronze metallurgy in this region, even when mixed with arsenical-bronze (Figure 76). Arsenical-bronze is the dominant alloy in all periods except the mid-3rd millennium BCE.

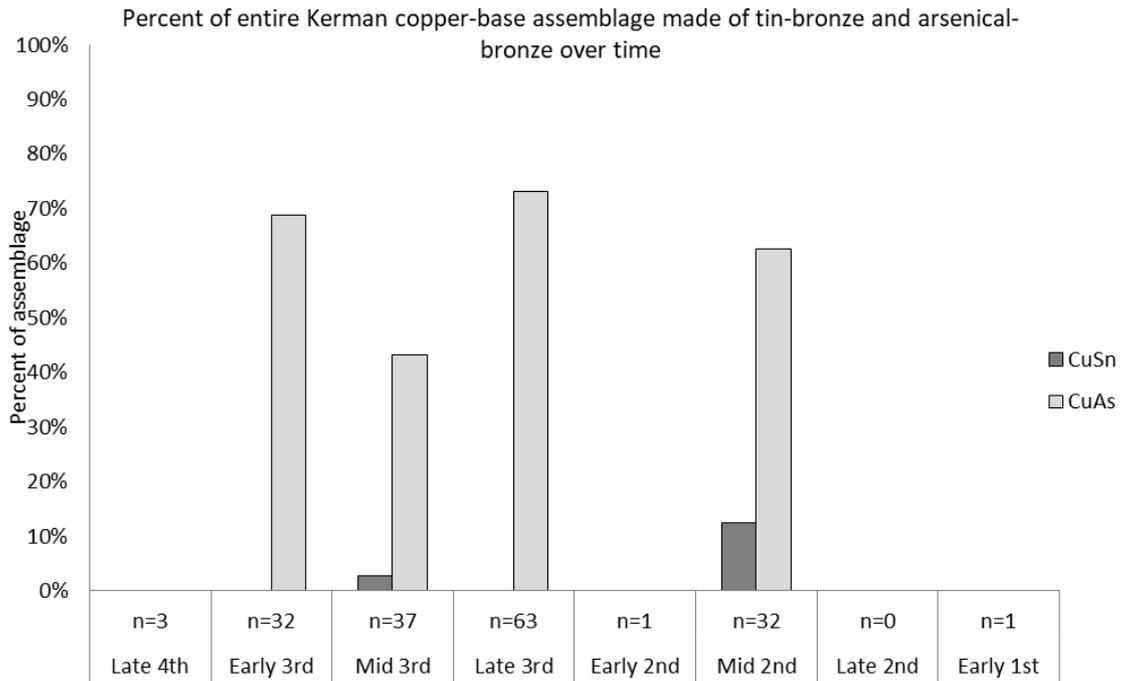


Figure 75: bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in Kerman

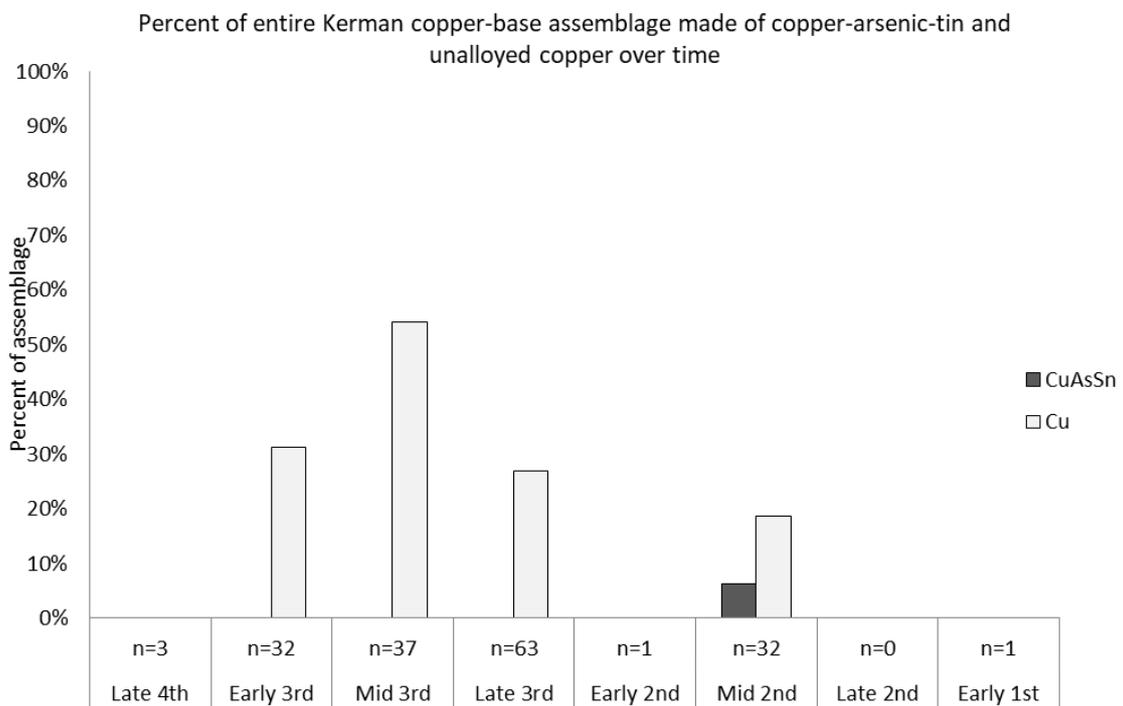


Figure 76: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in Kerman

13.2 Tin Content

The object (a figurine) made of tin-bronze from the mid-3rd millennium BCE contains 9.27% Sn, which is the highest value of tin in any tin-bronze object in the region. The three tin-bronze objects from the mid-2nd millennium BCE contain 1.25%, 7.62%, and 8.66% Sn. The copper-arsenic-tin objects contain 2.9% Sn and 1.08% As, 6.64% Sn and 1.14% As, and 8.3% Sn and 1.03% As. These values are low enough and varied enough to suggest imported and possibly recycled material, or at the very least a sporadic and experimental industry.

13.3 Copper Groups

Arsenic-only copper in each assemblage is always present between 34% and 47% over time (Table 18). The second most ubiquitous group is arsenic-silver, which seems to be more common in objects from modern Iran than anywhere else in Southwest Asia. In the earlier periods (late 4th millennium BCE to mid-3rd millennium BCE) there is more variety in copper compositions, but this ceases in the late 3rd millennium and mid-2nd millennium, indicating a change in stability or regional communication.

Table 18: Table depicting the entire Kerman copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi	Total
Late 4th	0%	33%	0%	0%	0%	0%	0%	33%	33%	0%	0%	0%	0%	0%	0%	0%	3
Early 3rd	6%	47%	0%	3%	3%	3%	0%	3%	9%	0%	9%	3%	0%	0%	13%	0%	32
Mid 3rd	38%	46%	0%	0%	0%	5%	0%	0%	3%	0%	5%	3%	0%	0%	0%	0%	37
Late 3rd	2%	46%	0%	2%	2%	3%	0%	0%	8%	0%	25%	5%	0%	3%	5%	0%	63
Early 2nd	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1
Mid 2nd	0%	34%	3%	0%	3%	6%	0%	0%	6%	0%	31%	3%	0%	0%	6%	6%	32
Late 2nd																	
Early 1st	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1

14 Eastern Arabia

14.1 Bronze ubiquity

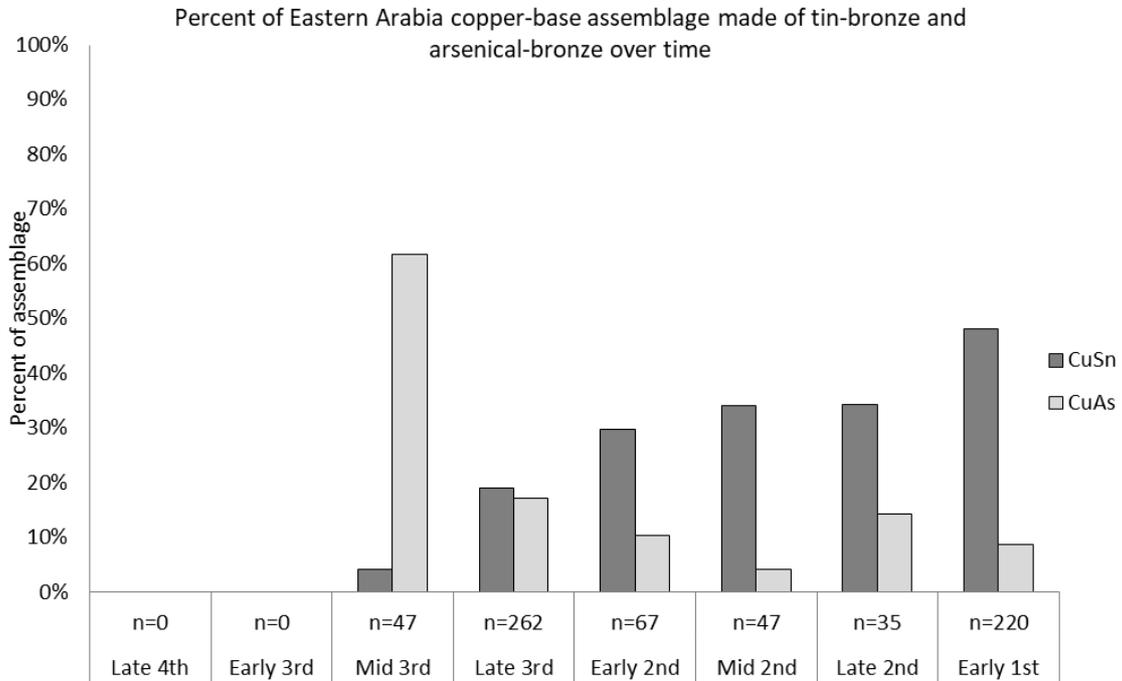


Figure 77 bar chart showing percent of assemblage made up of arsenical bronze (>1% As, <1% Sn) and tin bronze (>1% Sn, <1% As) in Eastern Arabia

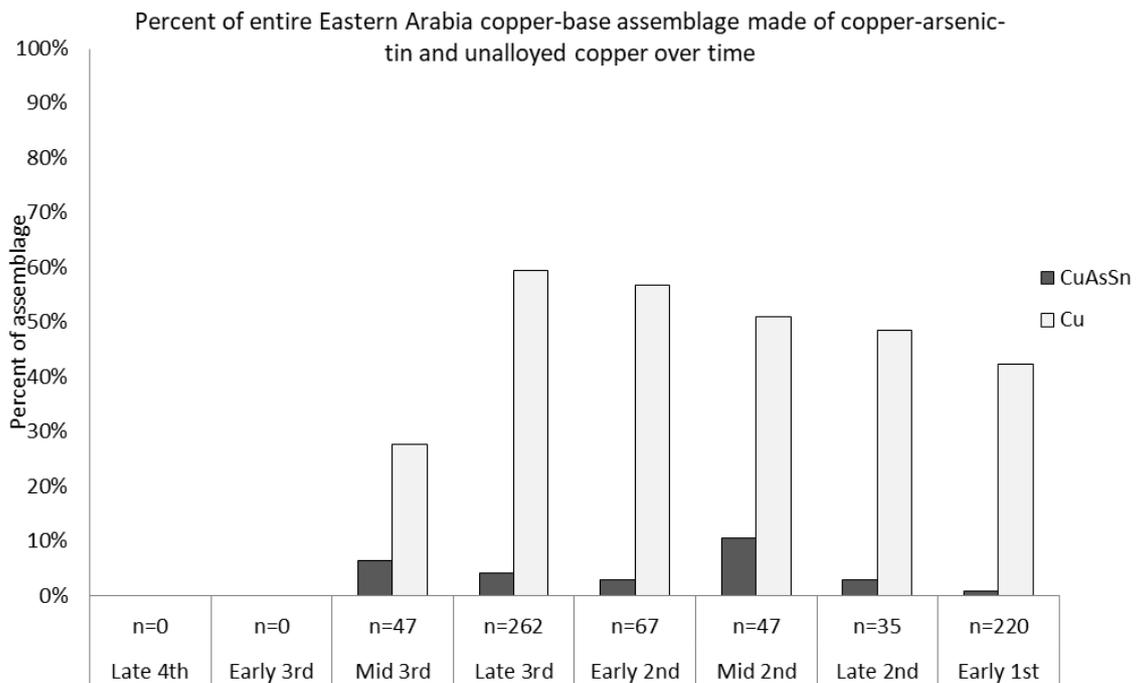


Figure 78: bar chart showing percent of assemblage made up of copper-arsenic-tin (>1% As, >1% Sn) and unalloyed copper (<1% Sn, <1% As) in Eastern Arabia

Arsenical-bronze constitutes over 60% of the assemblage in the mid-3rd millennium BCE (Figure 77), but this decreases substantially to 20% of the assemblage in the late 3rd millennium and continues to decrease until the mid-2nd millennium BCE to 17% of the assemblage. There is a slight increase in the ubiquity of arsenical-bronze in the late 2nd millennium, but this reduces at the beginning of the 1st millennium BCE. Tin-bronze use increases slowly over time, but at its most ubiquitous it only comprises 50% of the assemblage (early 1st millennium BCE). There is never a dominant tin-bronze tradition in the region, and it is worth noting that even the use of copper-arsenic-tin alloy was minimal in all periods (Figure 78). Unalloyed copper was the dominant material, though it slowly reduces from 60% of the assemblage in the late 3rd millennium to 42% in the early 1st millennium, indicating an increase in variation, experimentation or source material over time.

14.2 Tin content

28 of the objects from Eastern Arabian assemblage contain unusually high levels of tin (defined here 30% - 75% Sn) and all originate from the same two sites in Oman; Tell Abraq and Unar. It is not certain whether these objects originally contained such large amounts of tin, or if the copper in the sample corroded due to the acidity of the soil, leaving an emphasised composition of tin (Weeks 1997, p.76). If the tin-bronzes from this region had always contained such high levels of tin, it would be an extremely interesting regional difference in metallurgical tradition and access to raw materials. Studied in isolation, however, the values are so unusual that not much more can be said and these values cannot be relied upon.

When considered alongside data from neighbouring regions on the other hand, it is worth noting that several tin-bronzes from Mesopotamia contain up to 70% Sn, but these are not considered analytical anomalies, perhaps due to the Meso-centric nature of previous research. The possibility of intentionally high tin-bronzes (most frequently found in Oman but also known from other regions) is worth further investigation.

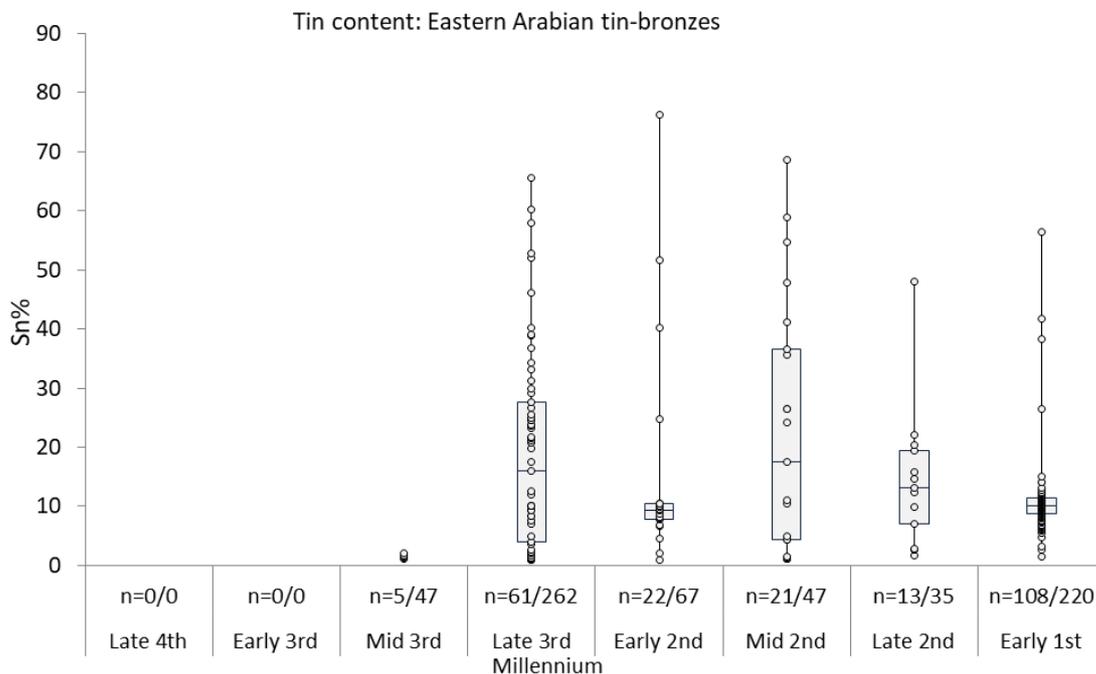


Figure 79: Box plot depicting tin content of all tin-bronzes (>1% Sn) from Eastern Arabia

Tin-bronze objects first appear in the region in the mid-3rd millennium BCE, though the five objects only contain between 1% and 2.1% Sn (Figure 79). In previous publications with tin classified as >2% Sn, the mid-3rd millennium tin-bronze assemblage would comprise only one object. Of all 62 objects in the late 3rd millennium BCE assemblage from Eastern Arabia Peninsula, only 7 objects do not come from Tell Abra q or Unar, therefore the large range of tin-contents and the high median might be considered unreliable. In the early 2nd millennium BCE half

the objects are clustered into a 3% range of variation, centred on a median of 9.4% Sn. There are only 3 objects containing >30% Sn in this assemblage, though there are 9 in total from Tell Abraq.

The enormous range of tin contents continues into the 2nd millennium BCE though settles into a smaller range by the later period. Despite a few high tin-bronzes in the early 1st millennium BCE, the tin-bronze industry appears to have settled into a more regular pattern, with the median and interquartile range focussed around 10% Sn, despite the presence of considerably more objects than in previous assemblages.

14.3 Copper Groups

Arsenic-nickel copper is the dominant copper composition in the region, varying from 44% of the assemblage to 57% (Table 19). Nickel-only copper is also a consistently major copper group after the early 2nd millennium and could be an indication of arsenic-loss over time. From the mid-3rd millennium to the early 1st millennium BCE, the ubiquity of copper group 1 ('clean' copper) gradually increases from 9% of the assemblage to 13% of the assemblage, possibly indicative of more intensive refining during the smelting process.

Table 19: Table depicting the entire East Arabian copper-base assemblage split into copper groups as designated by the 'Oxford technique'. Values indicate the percent of the assemblage assigned to each category

	Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAg	AsSb	AsAg	AsSbAg	Total
												g	Ni	Ni	Ni	gNi	
Late 4th																	
Early 3rd																	
Mid 3rd	0%	9%	0%	0%	4%	0%	0%	2%	0%	0%	49%	0%	0%	30%	4%	2%	47
Late 3rd	9%	7%	0%	0%	6%	0%	0%	1%	2%	0%	44%	0%	0%	7%	22%	2%	262
Early 2nd	6%	7%	0%	3%	21%	0%	0%	1%	1%	0%	57%	0%	0%	0%	3%	0%	67
Mid 2nd	11%	13%	0%	2%	17%	0%	0%	0%	0%	0%	55%	0%	0%	0%	2%	0%	47
Late 2nd	11%	14%	0%	0%	20%	0%	0%	0%	0%	0%	49%	0%	0%	6%	0%	0%	35
Early 1st	13%	12%	0%	1%	15%	1%	0%	1%	0%	0%	54%	0%	0%	3%	0%	0%	220

14.4 Arsenic, antimony, nickel, and silver content

If looking at the mean average content of arsenic (Figure 80), the arsenic content does not appear to be decreasing but remains relatively steady alongside the average nickel content, though there is a significant decrease of the median value of arsenic from the mid-3rd millennium to early 2nd millennium BCE. The average (mean) nickel content in objects from Eastern Arabia is consistently high in comparison to other regions in Southwest Asia and is frequently higher than the average arsenic content. These patterns are to be expected owing to the high arsenic and nickel found in many Omani copper ores. Both the average concentration of antimony and silver increase during the 3rd millennium BCE but are consistently rare.

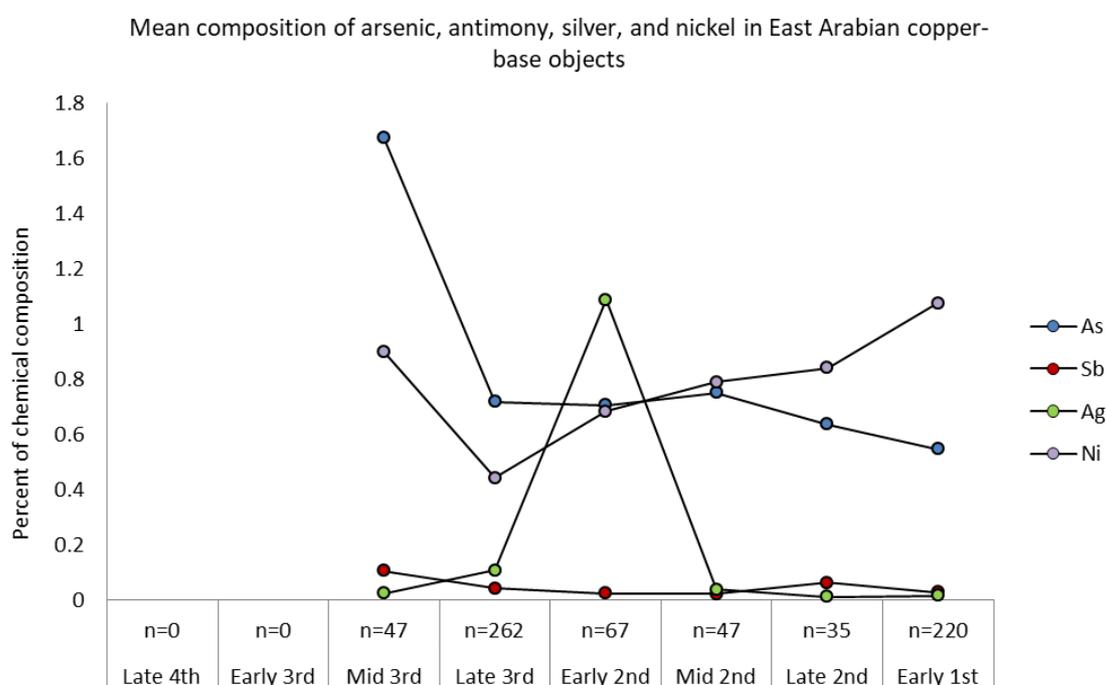


Figure 80: Line graph depicting the mean composition of arsenic, antimony, silver and nickel of all copper-base objects from Eastern Arabia

15 Chapter Summary

This brief description of metallurgical profiles emphasises the differing regional traditions across Southwest Asia. The regions located on the geographical edges of the study show the most differentiation; for example the dominance of 'clean' copper in the Southern Levant, the more frequent presence of silver as a trace element in regions located in Iran, the nickeliferous copper from Eastern Arabia, and the antimony-rich coppers of the Caucasus. The assemblages from the more centrally located regions of Southwest Asia tend to indicate a slightly more homogenised set of traditions and materials. The diversity of chemical patterns in Northern Mesopotamia is consistent with a region which acted as a thoroughfare for trade and exchange. Bronze traditions seem to vary much more by region, no doubt owing to access of tin or contact with greater trading partners.

It is necessary to look at isolated aspects of these regional traditions, however, to really understand the interconnectedness of practice and communication, and to attempt to define multi-regional traditions or the movement of material across Southwest Asia. Forming metallurgical profiles dependent on region does not give us insight into how the people of those regions interacted with the materials and knowledge available to them.

The aspect of these results which stands out on its own by comparison of regional tradition is that of very-high-tin bronzes. The numerous tin-bronzes containing >30% Sn found in Eastern Arabia have been relegated to anomalies which do not represent the actual tin traditions of the region, however there are multiple examples of objects containing >30% Sn from West and Central Anatolia, Cyprus, Northern Mesopotamia, Mesopotamia and Luristan which are not subjected to the

same dismissal. Unfortunately it is currently impossible to know whether all these objects are subject to the same effects of corrosion, or whether the high-tin content was intentional. One possible theory is that of intentionally high-tin objects intended as objects of trade, as the presence of copper would halt the process of tin disintegration. Further research is clearly needed but is outside the scope of this thesis.

Chapter Five: Alloying traditions of Southwest Asia

The study of alloying practices throughout prehistory can provide valuable insights into past conceptions of metal and specific characteristics of ancient metallurgy. This chapter addresses the inter- and pan-regional metallurgical traditions of Southwest Asia as exemplified by copper alloying from the debated beginnings of smelting through to the changed face of the early 1st millennium BCE. The chapter is structured chronologically but with specific focus given to points of contention at several stages throughout the time period. The first discussion centres on the perceived start of conscious metallurgical development: though secure evidence of smelting can be placed in the 5th millennium BCE there are isolated metallic finds from the preceding three millennia, which may indicate an earlier date (section one). The second section incorporates 4th millennium alloying traditions and attempts to discern accidental or deliberate motivation behind them, specifically focusing on the concept of experimentation.

From the 3rd millennium BCE onwards metallurgical tradition is perceived to be both deliberate and a motivational factor behind the forging of long-distance contacts. Section three therefore encompasses the culture expansions of the late 4th and early 3rd millennia BCE, and section four the consequent isolation of the Caucasus in the mid-3rd millennium BCE. Components of these events are visible in

the alloying traditions of the time and it is potentially possible to trace the extent of a culture and its contacts through a cohesive pattern of copper use at a given time. The tin-bronze traditions of Southwest Asia throughout the 3rd millennium BCE are then studied in order to reassess the potential of Kestel as a major tin supply, as the assessment of the evidence at the mine itself has so far been inconclusive (section five). During the 2nd millennium BCE the copper supply to Mesopotamia shifted from Magan copper to Cypriot copper: this clearly had an effect on the composition of copper in circulation, but also the circulation of tin in Southwest Asia, which was believed to have been imported via the Persian Gulf. Both of these results ought to be visible in the patterns of contemporary alloying traditions (section six). Section seven then addresses the changed face of emerging Iron Age metallurgical traditions after the collapse of the Late Bronze Age trading networks and centuries of de-urbanisation. In the final section additional elements which are considered non-traditional alloys, zinc and iron, are discussed in relation to the processes by which their presence was achieved, and considerations for further research.

The chapter as a whole presents analysis of patterns of preference, choice, and technological development in alloying practice from the accepted beginning of primary metallurgy through to the early 1st millennium BCE across Southwest Asia. During this time there were many changes in the treatment of copper-base material, either in terms of the conceptual approach to these materials, the resources used in production, the level of investment in skilled craft workers or the effects of regional prosperity on technological choice. Alloying elements in this chapter are considered as any combination of arsenic, antimony, silver, nickel,

iron, lead, zinc, or tin present at more than 1% in a copper-base object. Rather than a linear development from pure copper won from a simple smelt to alloyed copper smelted from complex ores, we can see a broad, precocious set of alloying practices in Southwest Asia from the very inception of metal technology.

1 8th to mid-5th millennium BCE: when did smelting technology develop?

In Chapter Two the current state of knowledge regarding the advent of smelting technology was outlined, including discussion of both *direct* and *indirect* evidence. The *indirect* evidence included highly contested 8th millennium BCE lead beads, a possible 7th millennium tin-bronze pin, and other assorted copper-base objects (Birch *et al.* 2013, p.308; Krause 2003; Garfinkel *et al.* 2014b). The *direct* evidence included a hotly debated piece of 7th millennium 'slag' from Çatalhöyük and 6th or 5th millennium BCE smelting crucibles from Tal-I Iblis (Kaptan 1990; Maddin *et al.* 1999; Roberts *et al.* 2009; Frame 2009; Weeks 2013; Hauptmann 2014; Craddock 2000). In this section, all pre-5th millennium BCE artefacts within the database will be considered after a brief discussion about the purity of native copper and its influence on the smelting debate.

Native copper is distinguishable from smelted copper owing to its distinctive microstructure, but this characteristic is lost if the native copper is melted down and cast (Craddock 2000). Some authors consider the chemical purity of copper to

be indicative of native copper (Birch *et al.* 2013; Levine 1999, p.184; Wertime 1964, p.1259). However this is inconsistent with the evidence in two ways: firstly, it is possible to produce copper without impurities from malachite (Killick 2014) and secondly, native coppers have been shown to contain high quantities of impurities, e.g. a native copper object containing 0.8% arsenic from Çayönü Tepesi (Krause 2003; Tylecote 1987, p.95 table 3.11; Özdoğan and Özdoğan 1999, p.14), though these 'impure' native coppers have been considered by some to be chronologically misplaced (Stech 1999, p.60). Early presence of copper alloys can therefore not be taken as indirect evidence of the earliest smelting technology as they could be natural, but nor should they be used as evidence that a chronological sequence is not accurate.

Lead does not occur in native form, and therefore its presence must be indicative of smelting technology (Krysko 1980, p.43; Stos-Gale and Gale 1981, p.181; Deming 2016, p.13; Heskell 1981, p.362). If the 8th millennium BCE lead beads from Çatalhöyük are accurately dated, then similarly dated copper-objects and potential smelting evidence could be considered as the possible inception of an isolated smelting technology. Another lead object is dated to 6th millennium BCE Yarim Tepe in Northern Iraq, contemporaneous with (though not proximal to) the smelting crucibles from Tal-I Iblis, Southeastern Iran (Gale and Stos-Gale 1981, p.181). Nor does native tin-bronze exist, indicating that the presence of tin-bronzes (if securely dated) could represent *indirect* evidence of smelting technologies. The tin-bronze pin from 7th millennium BCE Konyà, Anatolia, contains 8.4% Sn, and was found 114 km away as the crow flies from Çatalhöyük, where the possible 7th millennium BCE smelting evidence discussed above was

located (Krause 2003). Not much more can be said about this object owing to lack of references outside Krause (2003), though if it were found to be accurately dated it would necessarily indicate the advent of smelting, at least in Anatolia.

Table 20 presents all objects in the database dating to the 6th millennium and early 5th millennium BCE, and those which are unambiguously dated across the 5th and 6th millennia. Only two 6th millennium objects are represented in this database (not including the two objects from Echmiadzin which could belong to either the 6th or 5th millennium BCE). The remaining two 6th millennium BCE copper-base objects are tin-bronzes described by Garfinkel *et al.* (2014b): one is an awl from Tel Tsaf in the Southern Levant containing 6.6% Sn and the other a ring from Aruchlo I in the Southern Caucasus containing 8% Sn. These must represent smelted metal owing to the presence of tin and are therefore *indirect* evidence of technological change. The reliability of contextual information is pivotal if these objects are to be used as a foundation for the reconsideration of the earliest date of smelting technology.

The two 6th millennium BCE objects with chemical data presented in the database are from Kul'tepe in the Southern Caucasus and are broadly dated from 6000 to 5000 BCE; one is an arsenical-bronze containing 1.4% As and the other an arsenic-rich copper containing 0.4% As (Kashkay and Selimkhanov 1973). According to the conclusions of Birch *et al.* (2013), these objects must represent smelted copper owing to their high arsenic contents, though alongside the results of Tylecote (1987) and Özdoğan and Özdoğan (1999) they could be considered as native copper. The objects ultimately remain inconclusive additions to the debate.

Table 20: 5th and 6th millennium BCE copper-base objects from the database. N.B. “-” indicates no figure provided by analysts or authors, “0” indicates not detected or not present. (Object bibliography: Kashkay and Semilkhanov 1971; Thornton *et al.* 2002; Hauptmann and Pernicka 2004; Nezafati *et al.* 2008; Krause 2003)

Object	Site	Region	Start	End	As	Sb	Ni	Ag	Sn	Fe	Pb	Zn	
Unidentified Arrow	Kiultepe	S Caucasus	6000	5000	0.4 1.4	0.005 0	0.01 0.005	0.043 0.1	0.003 0.003	0.2 0.15	0.07 0.15	- -	
Four-sided awl Knife	Echmiadzin	S Caucasus	6000	4000	3.6 5.4	0 0	0.1 0.002	0.18 0.001	0.02 0.01	0.05 1.1	0.07 0.01	- -	
Hook	Tepe Yahya	Kerman	5500	4500	0.0642	-	-	-	-	-	-	0.0127	
Pin					0.0258	-	0.0423	-	-	-	-	-	-
Pin					0.0663	-	0.0405	0.0202	-	-	-	0.0211	
Tack			0.0552	-	0.0657	-	-	-	0.0673				
Awl			4500		0	0	0	0.01	0	0	0	-	
Wire			4500		0	0	0	0.03	0	0	0	-	
Axe-head	Unknown	Mesopotamia	5000	4000	0.82	0.05	0.25	0.03	0.001	0.001	0.62	0.001	
Bead Needle	Tepe Sialk	C Iran	5000	4100	0.077 0.22	0 0	0 0.022	0.01 0.003	0.002 0	0.078 1.38	0.002 0.023	- -	
Chisel	Arpachiyah	N Mesopotamia	5000	4000	0.1	-	-	-	0.0015	-	-	-	
Sceptre head	Can Hasan	W and C Anatolia	5000	4000	0	-	0.001	0.05	0	0	0	0	

The two copper-base objects from Echmiadzin (Southern Caucasus) are only very broadly dated from 6000 BCE to 4000BCE, so must be treated with caution. These objects contain considerably higher arsenic contents than seen in Southwest Asia thus far: an awl containing 3.6% As, and a knife containing 5.4% As and 1.1% Fe (Kashkay and Selimkhanov 1973). The possibility of native coppers containing high quantities of impurities has already been discussed but there was no mention of the upper possible limits of element quantity in the literature – at what quantity in the composition of native copper is an impurity considered so high it can only have been purposefully added (and therefore smelted), or perhaps there is no limit to native copper impurities. According to Mödlinger et al. (2017), arsenic present in such quantities as in the Echmiadzin samples would be sufficient to change the colour of the material, and according to Lechtman (1996) the quantity would be sufficient to change the working properties. If the objects had been smelted it could even be considered as intentional alloys (deliberate versus accidental alloying is discussed in full in the next section). One of the 6th/5th millennium objects contains 1.1% iron: the presence of iron is indicative of smelting, and its detrimental effects are noticeable at 1% (Craddock and Meeks 1987). The knife, at least, was probably smelted but again its lack of a secure chronological context does not add anything to the debate.

There are six objects dating to the late 6th/early 5th millennium BCE (an awl, a wire, a tack, a hook, and two pins) from Tepe Yahya in the Kerman region of Iran (Thornton *et al.* 2002). All of these contain very low levels of impurities and represent very small objects which could have been hammered from lumps of native copper. The two 5th millennium objects from Tepe Sialk (Table 20) also

represent the style of objects that are commonly made of native copper. However the needle contains 1.38% Fe making it likely to have been produced by smelting. The axe-head, chisel, and sceptre head from Mesopotamia, Northern Mesopotamia, and Anatolia (Table 20) are also broadly dated to the 5th millennium BCE but represent completely different manufacturing techniques. These objects must have been made at least from molten and cast metal, though the levels of impurities (low in the chisel and sceptre head, high in the axe-head) do not help us ascertain whether the objects were smelted or made of amalgamated and melted native copper.

It is generally believed by most that by the end of the 5th millennium BCE smelting was occurring on a wide scale. However evidence for smelting operations at this time is still limited to only a handful of sites across a very large region and it cannot be assumed that the products of those operations would reach into all corners of Southwest Asia. Apart from finds of actual production debris, the oft cited reason for the belief that smelting was occurring on a wide scale by this time is the presence of impurities within the copper composition. If, as discussed earlier in this section, native copper cannot be established by virtue of its purity, then neither can the advent of smelting be demarcated by the presence of impurities. Therefore the following objects, although more likely to have been smelted than in previous periods, may still represent the use of native copper.

The largest number of late 5th millennium copper-base artefacts come from Mentesh-Tepe in the Southern Caucasus and are dated between 4500 and 4000 BCE (Courcier *et al.* 2012), though in Lyonett *et al.* (2016) it is stated that no copper was found at this site. A large majority of these object are awls and rings,

which could be indicative of native copper hot-working technology, however there are also a number of prills and agglomerations of prills, one of which contains 15% Fe and was therefore certainly smelted. There are many other objects with traces of iron present at the site, though as they are present <0.5% may reflect simple impurities. It is possible that smelting took place on-site as a small piece of azurite was discovered there: however no contemporary ceramics with smelting residue were found (Lyonnet *et al.* 2016). Other objects from this time period are also suggestive of smelted rather than native copper: the axe/adze-heads from Tepe Gaura in Northern Mesopotamia (one of which contains traces of iron, and the other being an arsenic-nickel-copper alloy); and two pins from Tepe Hissar, one of which is a tin-bronze (2.12% Sn), and the other of which is a leaded-tin-bronze (1.52% Pb and 1.74% Sn).

To summarise, the *indirect* evidence of 8th to 5th millennium BCE copper object finds still provides ambiguity on the question of whether smelting occurred before the mid/late 5th millennium BCE, although objects dating to the late 5th millennium BCE show more indications of having been smelted. Impurities such as arsenic cannot be used to differentiate between smelted copper and melted native copper, though two objects which are broadly dated to the 6th and 5th millennia could potentially contain enough arsenic to be indicative of deliberate alloying, which would suggest smelting technology. Three objects from Mesopotamia, Northern Mesopotamia, and Anatolia could represent melted and cast native copper, or smelted ore. On the other hand two tin-bronze objects (from the Levant and Caucasus) must have been smelted as they are made of a non-natively occurring material. The ambiguities provoked by the presence of pre-5th millennium BCE

objects mean they should not be ignored in the search for the earliest development of smelting, and objects containing characteristics outside the realm of native copper should not be dismissed as being out of context. It is hypothesized here, owing to the number of finds and crucible evidence discussed in Chapter Two, that smelting technology was likely to be developed in the 6th millennium BCE though perhaps in isolated contexts. It was not until the 5th millennium BCE that the technology appears to have been adopted on a wider scale or undertaken in more organised contexts.

2 4th millennium BCE: Accidental, deliberation or experimental alloying?

Once smelting-technology was well underway it remains to be seen how the technology was approached by ancient craftspeople. Traditionally the archaeometallurgical view was that smelting began with simple smelts of pure copper ore, such as malachite, into relatively pure copper. However 45% of all copper-base objects from the early 4th millennium BCE contained >1% of either arsenic, antimony, silver, nickel, iron, zinc, lead, and/or tin, and by the late 4th millennium BCE this percentage had risen to 70% of the copper-base assemblage (Figure 81). Were ancient metalsmiths actively seeking or creating copper alloys for the improvement of aesthetic or behavioural properties and consequently *deliberately* manipulating the material produced, or was it a product of smelting

local, available ores and the widespread appearance of so many alloying elements the product of an *experimental* phase?

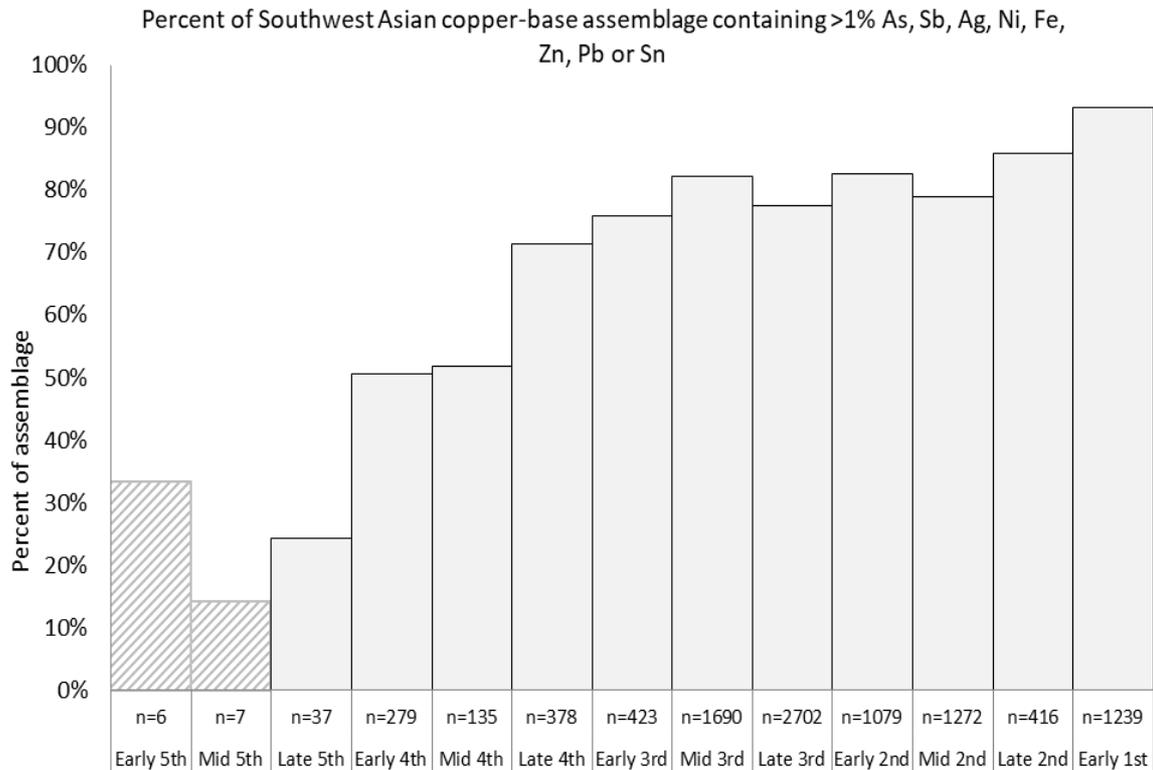


Figure 81: Percent of the entire Southwest Asian copper-base assemblage containing >1% of one or more of the alloying elements from the 5th millennium to the 1st millennium BCE

Several issues need to be addressed in order to begin dissecting past approaches to early smelting technology. Firstly, what is meant by *deliberate* and *accidental* alloying, and how might we be able to distinguish these processes through the chemical data? Secondly, what is meant by an ‘experimental phase’, and how this can be applied to both *accidental* and *deliberate* alloying traditions?

Accidental or fortuitous alloying would presumably include smelting a copper ore that looked similar to malachite or azurite, or serendipitously co-smelting a combination of oxides and sulphides, with the result being a copper alloy which

the craftsman had not intended to produce. *Deliberate* alloying is obviously a conscious choice of material or an intended material result and can be achieved in one of three ways. First, co-smelting two ore types or deliberately choosing an ore which produces a product known to be distinguishable from pure copper. This route is the most similar to *accidental* alloying and could represent a choice made by someone who has only recently accidentally smelted an alloy. Second, the intentional addition of arsenic, antimony, or tin ore to the copper smelt or pre-smelted metallic copper (mixing of two metallic components would also be included in this form of alloying, though it represents a separate stage of the technological process). Third, the addition of speiss, most often referred to in the case of arsenic alloys.

One problem with the description *accidental* alloying is that though the ore or combination of ores could have been smelted unknowingly, the craftsman may still have recognized the improved behavioural properties of the metal *once it was made*. It therefore does not necessarily mean that the way *accidental* and *deliberate* alloys were utilized and manufactured into objects will be separable by comparing object type and chemical composition. An *accidentally smelted* alloy could be a *deliberately used* alloy.

Throughout this section the concept of the 4th millennium BCE as an 'experimental phase' of metallurgy will be put forward, but first several aspects must be outlined. As in Weeks (2013, p.286) 'experimental' here does not refer to modern scientific experimentation but processes of human curiosity into the transformation of mineral into metal. The term could also apply to both *deliberate* and *accidental* alloying. However it could also represent a stage in-between both:

experimentation with ores clearly does not represent an uninformed choice of ore, since this would include an unwieldy number of all rocks to choose from: the metalworkers must have had some prior knowledge regarding material choice. The resulting alloy may therefore be unknown and fortuitously improved in terms of mechanical properties, but the mixture of ores was deliberately put together. It does not necessarily have to represent a fully informed choice, or the craftsperson might simply stop experimenting when a sufficiently useful mixture of ores was found. Experimentation would appear to be driven by curiosity rather than necessity or practicality.

The chemical results of an experimental phase of alloying and smelting might be the presence of various differing alloying elements present in the copper-base assemblage in varying quantities. We might also expect to see certain regional differences as experimentation would be limited by regional ore composition, or trading contacts with other regions with regional ore compositions. An experimental alloying phase may also explain the early, but rather randomly located, instances of tin-bronzes (discussed below).

2.1 A theoretical paradigm of an experimental phase

The varied use of native copper and 'greenstone' in pre-metallurgical contexts is frequently discussed in the literature concerning early metallurgy, partly to illustrate craftspeople's familiarity with the newly adopted material, but also to highlight the apparent importance placed on the colour of minerals. Radivojević

and Rehren (2016, p.266) conducted research into the collection of copper ore at Vinča Culture sites in modern Serbia and on the basis of their strong preference for black and green ores, the authors argue that it was the “combination of colours [which] drove the experimental phase”. The blue-green colour of flames once malachite has been added is also mentioned, and its historical importance for distinguishing minerals has long been noted (Charles 1985). In addition to the possibility of flame testing minerals by grinding them to powder and

Table 21: Diagnostic colours of common metals in use during the Bronze Age when applied to the flame test

Element	Flame colour
Arsenic	Blue
Copper (I)	Blue
Lead	Blue
Zinc	Blue-green
Copper (II)	Green
Iron (II)	Green
Antimony	Pale green
Tin	Blue-white
Nickel	Silver-white

throwing a handful onto a flame, it is also possible that they carried out a streak test by running the mineral across a harder, darker stone containing some silica (Oddy 1986, p.166). Furthermore, it need not only be the distinctive blue-green of copper itself which comes into focus – all elements which were alloyed with copper during the Bronze Age produce a colour along the blue-green range in a flame test, as can be seen in Table 21.

Knowledge that a number of minerals producing a green/blue flame could be smelted to produce a variant of copper would allow early smelters a certain amount of freedom to experiment successfully and could explain the early onset of alloying practice. Tin, antimony, and nickel produce quite light-coloured flames,

perhaps unnoticeable in the flames of a fire rather than a Bunsen burner. As often discussed, malachite³ is bright green, produces a light green streak, and a blue-green flame; azurite⁴ is blue, produces a light blue streak, and blue flames; olivenite⁵, an example of an arsenic-rich copper mineral which can produce arsenical-copper in a one-step smelt, is green to green-brown, produces a yellowish green streak, and its individual components provide a blue-green flame.

If this theoretical approach by ancient smelters is feasible, it could lend weight to the argument for the use of stannite⁶, or polymetallic deposits containing tin, in the production of early copper-tin alloys (Helwing 2009, p.211; Radivojević *et al.* 2013, p.1040). Rovira *et al.* (2009) have shown that it is possible to co-smelt a copper-tin alloy from a mixture of copper ore and cassiterite. Before discussing the possibility of accidental/experimental smelting of copper-tin alloys, the process of oxidisation of primary ore minerals and the build-up of polymetallic ore deposits will briefly be outlined. As the geology of tin deposits is rarely studied in relation to Southwest Asia due its lack of economically viable deposits in the modern day, this section refers to a study of polymetallic tin mineralization in China (Wang *et al.* 2007). These authors studied tin-polymetallic deposits occurring in volcanic to shallow subvolcanic settings, and they state that polymetallic minerals and tin are known to form a sulfidic ore body, often containing Pb, Zn, Cu and Sn. The weathering of such deposits often results in a mixture of oxide minerals which can be easily smelted (Wang *et al.* 2007, p.284). Therefore a mineral deposit of stannite, which

³ Malachite: $\text{Cu}_2\text{CO}_3(\text{OH})_2$

⁴ Azurite: $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$

⁵ Olivenite: $\text{Cu}_2\text{AsO}_4(\text{OH})$

⁶ Stannite: $\text{Cu}_2\text{Fe}^{2+}\text{SnS}_4$

often occurs alongside chalcopyrite⁷, pyrite⁸ and arsenopyrite⁹ (*Mindat.org* 2018), exposed to frequent rain and humidity could ultimately form a deposit containing both malachite and oxidised stannite. This combination could result in a single step smelt to produce tin-bronze with variable amounts of tin and other elements (e.g. iron or arsenic) depending on the character of the primary deposit.

Mushistonite¹⁰, a secondary product of stannite which was only characterized in the early 1980's, is itself often described as "malachite-green" (*Webmineral.com* 2018) – and produces a light blue-green flame when ignited. It is easy to imagine how such a mineral, or a similar variant of oxidized tin-copper ore, could have been mistaken for (or even smelted as) malachite.

This is not to suggest that craftspeople were ignorant of the difference between either the mineral or the resultant metals, nor that they worked exclusively with blue-green materials, especially as the longer metallurgy was developing the more familiarity and experience the metalsmiths would have with all related materials. Rather this concept is aimed at suggesting that the colour spectrum of blue-green provided a reliable parameter within which to seek new minerals or experiment with new forms of copper-alloy and metallic qualities. This conceptualization of minerals would also have more easily enabled the transmission of metallurgical knowledge between communities and further afield.

⁷ $\text{Cu}_2\text{Fe}^{2+}\text{S}_2$

⁸ Fe^{2+}S_2

⁹ Fe^{3+}AsS

¹⁰ $\text{Cu}_{0.5}\text{Zn}_{0.4}\text{Fe}^{2+}_{0.1}\text{Sn}(\text{OH})_6$

2.2 Early occurrences of tin-bronze

Figure 82 is a map depicting the known locations of all pre-3rd millennium BCE tin-bronzes within the database collected for this thesis. The pre-4th millennium BCE objects are not included as they have been discussed in previous sections. Following on from the discussion of experimental smelting, and *deliberate* or *accidental* smelting, tin-bronzes are considered as containing >0.5% Sn, as in order to achieve this quantity of tin some form of tin ore must have been present. First, this section will cover the Mediterranean Region of Anatolia, given the proximity of two sites which produced multiple examples of copper-tin, both with each other and a stannite source, before moving on to address 4th millennium BCE tin-bronzes across the wider region of Southwest Asia.

Yümüktepe (3900 – 3800 BCE) and Gözlükule (3200 – 3000 BCE) in the Mediterranean region of Anatolia provided the largest individual assemblages of early tin-bronze objects; more than any other contemporary site. Though the sites are separated by 600 years or more, they are mentioned together since they are located only 33 km apart from one another, and 72 km to 65 km distant from Madenköy, a potential source of stannite (Öztürk and Hanilci 2009, pp.109–10). As mentioned in section 2.1 of this chapter, it is possible for stannite to oxidise in the right climatic conditions. The climate of the mountainous regions of Anatolia is predominantly rainy and humid (Atalay *et al.* 2014), which is optimal for the oxidisation of sulphide ores, perhaps explaining why early tin-bronzes are more often found in Anatolia during this time than anywhere else.

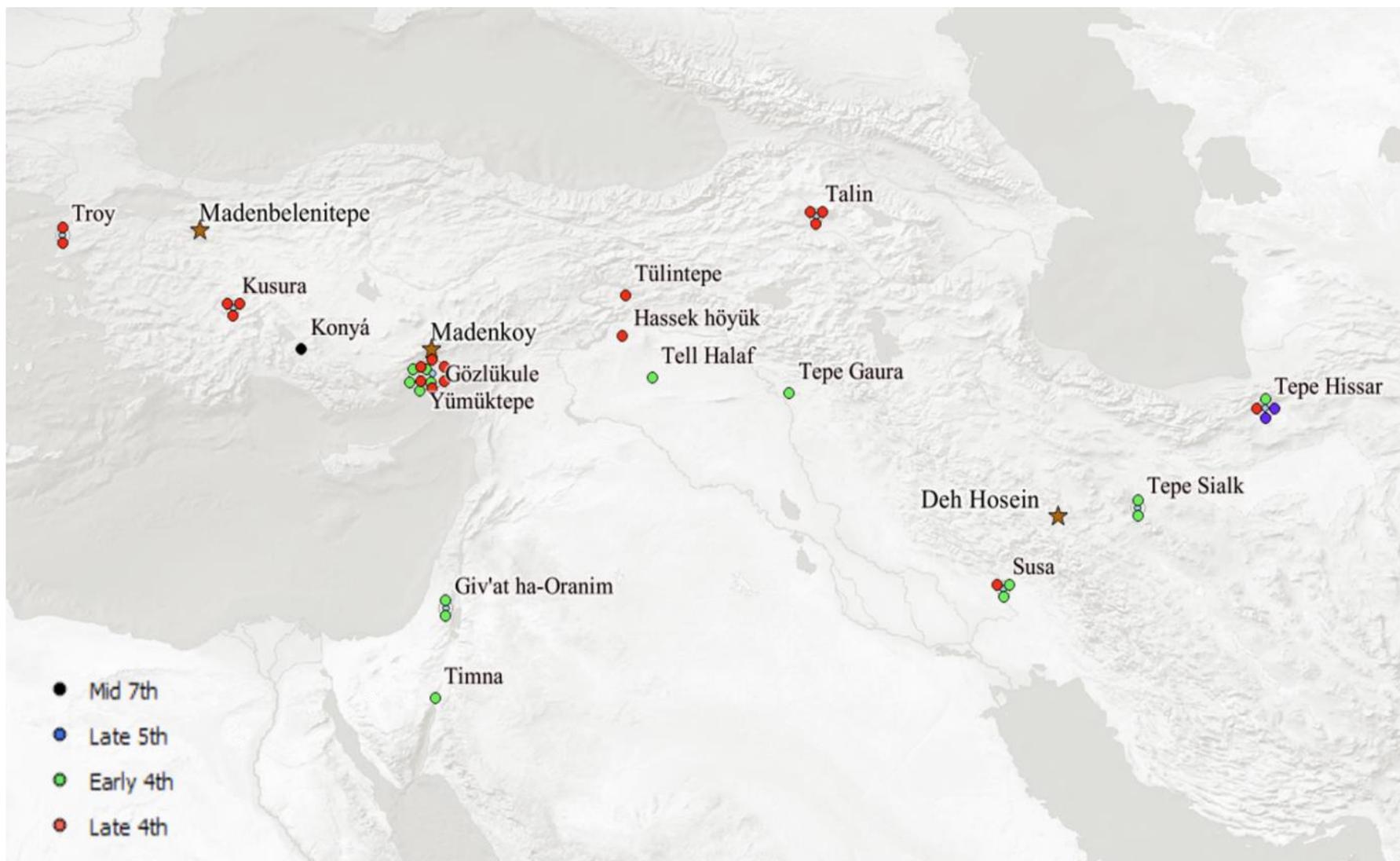


Figure 82 Map of all objects from pre-3rd millennium BCE contexts containing >0.5% Sn split by time period, also included are known locations of occurrences of stannite.

Table 22: 4th millennium tin-bronze objects from Yümüktepe and Gözlükule and the most common alloying elements. (Object bibliography: Krause 2003)

	Start	End	Provenance	Object	Sn	As	Sb	Ni	Ag	Pb
Early 4 th	3900	3801	Yümüktepe	Sickle	0.55	0.97	0.02	0.04	0.05	0.08
				Roll headed pin	0.75	1.1	0.58	0.19	0.04	0.18
				Solid needle	1.3	1.15	0.46	0.23	0.04	0.02
				Awl	2.1	1.25	0.28	0.27	0.04	0.18
				Unidentified	2.6	1.2	0.05	0.06	0.03	1.55
Late 4 th	3200	3001	Gözlükule	Flat chisel	0.84	1.1	0.44	0.32	0.03	0.09
				Awl	1.1	3.2	0.6	0.13	0.04	0.06
				Sewing needle	1.6	1.15	0.38	0.32	0.21	0.02
				Flat chisel	2.5	0.59	0.26	0.18	0.05	0.35
				Flat chisel	4.9	1.4	0.04	0.16	0.13	2
				Knife	6.6	1.05	0.03	0.04	0.44	0.43

According to Kuijpers (2017) and Mödlinger et al. (2017) only tin present in quantities greater than 5% is noticeable by metalworkers. All five Yümüktepe tin-bronzes from the early 4th millennium BCE are well below this threshold, the highest tin content being 2.6%. What is particularly noticeable about the trace element composition of these tin-bronzes (Table 22) is the ‘alloying quantities’ of arsenic, and the high trace levels of antimony, nickel, and lead in most of them. It is not known what effect a cumulative concentration of impurities has on the recognizable behavioural or aesthetic properties of copper. The number of impurities present in the tin-arsenic-bronzes could indicate a polymetallic ore source. The low quantities of tin certainly suggest the material could have been accidentally or experimentally smelted. Not much can be said about the choice of material alongside object typology, as the remaining copper-base assemblage (sixteen objects) predominantly consists of pins, awls, needles, and a sickle, which directly reflect the tin-arsenic-bronze assemblage. However, there are also four axes made of unalloyed copper which variously contain trace levels of antimony, arsenic, and silver, but no nickel, lead, or tin, and the arsenic contents are significantly lower than in the tin-arsenic-bronzes. Larger, more complicatedly

fabricated objects were apparently not restricted to alloyed copper at this stage in the Mediterranean Region, possibly suggesting that the behavioural qualities of alloyed material were not realised.

Six hundred years after tin-bronze use at Yümüktepe, the site of Gözlükule adopted tin-bronze (Table 22). Six of fifteen objects contain >0.5% Sn; an awl, a needle, a knife, and three chisels. The chisels, and possibly the knife, represent the use of casting technology. It is interesting to note that the knife and one of the chisels contain perceptible levels of tin (4.9% and 6.6% Sn). This could suggest that the metalsmiths had made a deliberate decision to use a material with better casting properties for larger objects. It is also possible that the same, or a proximal, polymetallic ore source was exploited across the 4th millennium BCE, and that over time the improved properties of tin-bronze began to be recognized by the craftspeople.

If we take a more widespread view of tin-bronzes from early 4th millennium BCE Southwest Asia, it is clear that some objects contained perceptible levels of tin as marked in gold on Table 23. None of these objects are tin-arsenic-bronzes as in the Mediterranean Region and they also have considerably fewer impurities, though the number of objects containing lead (and higher lead quantities) is larger in modern Iran and Iraq than Anatolia. There is only one tin-bronze object containing arsenic dating to the early 4th millennium BCE outside Anatolia: an adze-head from Susa, which is rather an arsenic-nickel-copper alloy containing a significant tin impurity. A disk from Tepe Hissar and an awl from Giv'at ha-Oranim are actually leaded-tin-bronzes. Though the number and quantity of impurities is different from those in the tin-bronze objects at Yümüktepe, the variation and variability

still could be suggestive of polymetallic ores and indicate local experimentation rather than objects traded from a specific region.

Table 23: early 4th millennium BCE objects from Southwest Asia. N.B. “-“ indicates no figure provided by analysts or authors, “0” indicates not detected or not present, objects highlighted in gold indicate those with perceptible levels of tin, grey: >0.1% of impurity element.

	Provenance	Larger Area	Object	Sn	As	Sb	Ni	Ag	Pb	Fe
Early 4 th	Susa	W Elam	Adze-head	0.82	3.5	0.5	2.5	0.08	0.81	0.6
	Tepe Sialk	C Iran	Awl	0.95	0.56	0.24	0.08	0.04	0.15	0.21
			Awl	2.5	-	-	-	-	2	-
	Tepe Hissar	Casp Coast	Disk	1.53	-	-	-	-	1.49	0.001
			Pin	3.89	0.5	0.03	0.122	0.04	1.11	0.06
	Giv'at ha-Oranim	S Levant	Axe	4.907	0.646	0.02	0.156	0.485	0.596	0.058
	Tepe Gaura	N Mesop	Pin	5.62	0.67	0.09	0	0	0.24	0.04
	Timna	S Levant	Needle	6.1	0.015	0.015	0.02	0.02	0.17	1.7
	Susa	W Elam	Adze-head	14.2	0.86	0.05	0.48	0.03	0.005	0.31
	Tell Halaf	N Mesop	Flat axe	14.5	0.17	0	0.2	0.01	0.14	0

The overall Southwest Asian tin-bronze assemblage in the early 4th millennium BCE, though contemporary with Yümüktepe, seems to show a more deliberate application of alloyed materials to certain typological forms. This is also more prominent in eastern regions than towards the west. Three of the objects containing perceptible levels of tin are axes. In fact the two axes from Susa and Tell Halaf contain ~14% Sn, which would definitely be sufficient to be considered a separate metal by the craftsperson and could even represent the direct addition of tin or a tin-ore to copper. Apart from one object from the Southern Levant the objects containing imperceptible levels of tin are mostly from Iran.

In the late 4th millennium BCE, sites containing tin-bronzes in the copper-base assemblage (contemporary with the Gözlükule assemblage) are more often located in northern regions rather than southern, opposite to what is seen in the early 4th millennium BCE (Table 24). Almost half the late 4th millennium copper-tin

assemblage are tin-arsenic-bronze, suggesting this combination is perhaps connected loosely with northern ore deposits as tin-arsenic-bronze was not as common in predominantly southern early 4th millennium copper-tin assemblage. During the late 4th millennium BCE tin-bronzes were frequently manufactured into larger and/or higher status objects, such as weaponry and spiral rings, although West and Central Anatolian tin-bronze objects were still predominantly tools.

Table 24: late 4th millennium BCE objects from Southwest Asia. N.B. “-” indicates no figure provided by analysts or authors, “0” indicates not detected or not present, objects highlighted in gold indicate those with perceptible levels of tin, grey: >0.1% of impurity element.

	Provenance	Larger Area	Object	Sn	As	Sb	Ni	Ag	Pb	Fe
Late 4 th	Tepe Hissar	Casp Coast	Bracelet	0.63	4.2	0	0.02	0.02	0.07	0.001
	Hasek höyük	E Anatolia	Small dagger	0.69	0.614	0.0161	0.297	0.0624	0.0121	0.0075
	Talin	S Caucasus	Spearhead	0.71	2.09	0.0278	0.07	0.166	0.05	0.045
			Spearhead	1.35	1.69	0.054	0.049	0.46	0.03	0.08
	Kalleh Nisar	Luristan	Finger ring	3.52	0.96	-	0.24	-	0.29	0.31
	Tülintepe	E Anatolia	Roll headed pin	5.27	0.55	0.029	0.21	0.039	0.043	0.28
	Susa	Western Elam	Pin	5.3	0.55	0.45	0.08	0.09	15.1	0.12
	Kusura	W&C Anatolia	Awl	5	0.27	0.00025	0.0005	0.03	0.12	-
			Solid needle	6	0.67	0.04	0.1	0.77	1.55	-
			Awl	6.7	1.35	0.05	0.17	0.0005	0.29	-
	Troy		Flat chisel	6.4	1.2	0.02	0.14	0.07	0.84	-
			Flat chisel	8.2	0.63	0.017	0.11	0.038	0.12	0.14
	Talin	S Caucasus	Spiral ring	11	0.4	0.032	0.34	0.2	0.21	0.15

Kusura and Troy are reasonably close to another possible source of stannite mentioned in the literature, and all tin-bronze objects from these sites contain between 5 and 8.2% Sn (Begemann *et al.* 2003). The typological allocation of tin-bronzes from Talin in the Southern Caucasus indicates experience of mechanical properties or exploitation of the aesthetic qualities and its role in the decision-making process: the two spearheads are tin-arsenic-bronzes though contain more arsenic than tin. The spiral ring, on the other hand, contains 11% Sn which would greatly affect the appearance of the object.

In comparison to the early 4th millennium BCE tin-bronze tradition in Southwest Asia, there was apparently more control or knowledge exercised over use or

choice of ores or use of material in the second half of the millennium. These assemblages could of course represent the beginning of tin being imported into the region, or the beginning of a tin industry which used added tin from local sources to create a mixed material, but it is only really in West and Central Anatolia that tin-bronze metallurgy continues uninterrupted into the 3rd millennium BCE (see section 5, this chapter).

2.3 Extraordinary alloying practice in the early 4th millennium BCE

Before moving on to discuss 4th millennium BCE alloying techniques, a brief explanation of how to read the alloying maps (e.g. Figure 83) presented throughout the remainder of this chapter is necessary, as they are not intuitive. Each dot represents an object or number of objects. The dots do not represent the location of specific sites. The objective of these maps is to represent copper alloys *within* the regional assemblage. The sizes of the dots are graded to represent the number of objects made of that specific copper composition. Each colour represents an alloying element (present in the copper object at >1%). The differing sample sizes has negated the possibility of a simple scale of size to reflect the number of objects, and therefore has been divided into blocks of 1, 5, 10, 20, 50, and 100: where there are multiple dots of the same colour or same combination of colours, this is to accurately reflect the number of objects with that alloy present (e.g. two size 10 dots and 4 smallest size dots equal 24 objects in the assemblage made of that copper composition).

The data has been represented in this way partly owing to space – there are too many possible combinations of the seven alloying elements to produce a meaningful pie-chart for each region’s copper alloying assemblage. It is also not possible to show the percentage of each alloying element separately in a series of maps for two reasons; firstly, this would eventually provide seventy maps when all seven elements are shown for each of the ten time periods, which is far too cumbersome to display; and secondly, this system completely overlooks the prevalence of certain combinations such as arsenic-antimony, arsenic-nickel or lead-zinc. The aim of these maps is to highlight where certain alloying elements and combinations of these elements are most regionally common and to emphasize changes over time as some are replaced or display patterns of longevity. It also enables the visual representation of the occasional object which contains a combination of five alloying elements, which owing to their infrequency and random assortment of alloying elements is presumed to indicate mixing or recycling of scrap copper.

The second case study presented in this chapter of the exploration of deliberate, accidental, and experimental approaches to alloying are represented by the early 4th millennium BCE Southern Levant assemblage of extraordinary copper-alloys (Figure 83). Nearly half this copper-base assemblage contains arsenic, and most of those also contain antimony in extremely high quantities. The unusual objects represented in this period are not only from the Nahal Mishmar hoard but also from Nahal Zeelim, Giv’at Ha Oranim, and Shiqmim (Shalev and Northover 1993; Namdar *et al.* 2004; Golden *et al.* 2001; Shalev *et al.* 1992). Though both arsenic and antimony are common in alloying quantities (>1%) throughout Southwest

Asia from the earliest objects to the early 1st millennium BCE, the sheer number of arsenic-antimony-copper alloy objects and the high element composition is unmatched at any other time in any other region. These objects clearly represent deliberate alloying, and possibly enrichment, as no known ore would provide these quantities in a natural smelt and they therefore characterise an experimental and innovative regional approach to material. The object types and sites that the objects originate from are represented in Table 25.

Table 25: Southern Levant copper-base assemblage dating to the early 4th millennium BCE, depicting the number of objects present in each site and describing its typology

Category	Ceremonial			Dress	Container	Metallurgical		Tool					Weapon	Other
	Crown	Macehead	Standard	Pin	Vessel	Prill	Piece	Blade	Chisel	Awl	Needle	Scraper	Axe	Unknown
Faynan														1
Ghassul								1						
Giv'at ha-Oranim	5	10	12	2			7		2	2		2	5	
Nahal Mishmar	1	10	1		1									
Nahal Zeelim		3											1	
Shiqmim		3					1							2
Timna											1			
Wadi Fidan														13
Total	6	26	13	2	1	1	7	1	2	2	1	2	6	16

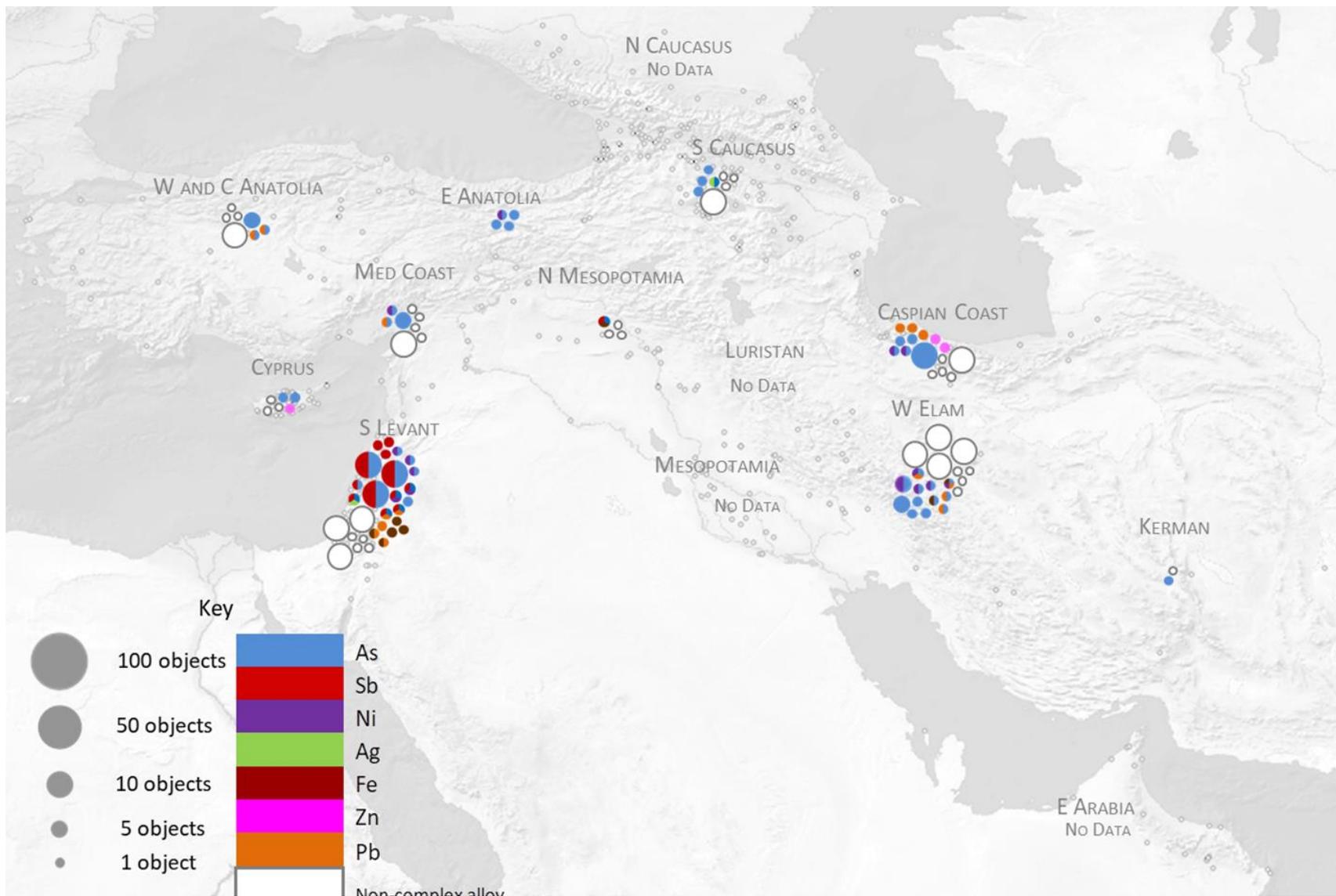


Figure 83: early 4th millennium BCE regional copper-base assemblages indicating alloying elements in use (alloying elements considered as >1% As, Sb, Ni, Ag, Fe, Zn, Pb, and 'unalloyed copper')

Figure 84 shows the correlation between arsenic and antimony in these Southern Levant copper-base objects by typology. The category 'ceremonial equipment' includes maceheads, crowns, and standards, and it is mainly these items and one container which show a correlation between antimony and arsenic. Unfortunately the ceremonial objects vastly outweigh any other typological category and so a full comparison is not possible. However the tools, weapons, and uncategorized objects are mostly to be found at the low-antimony, low-arsenic zone of the chart (indicated by crosshatching).

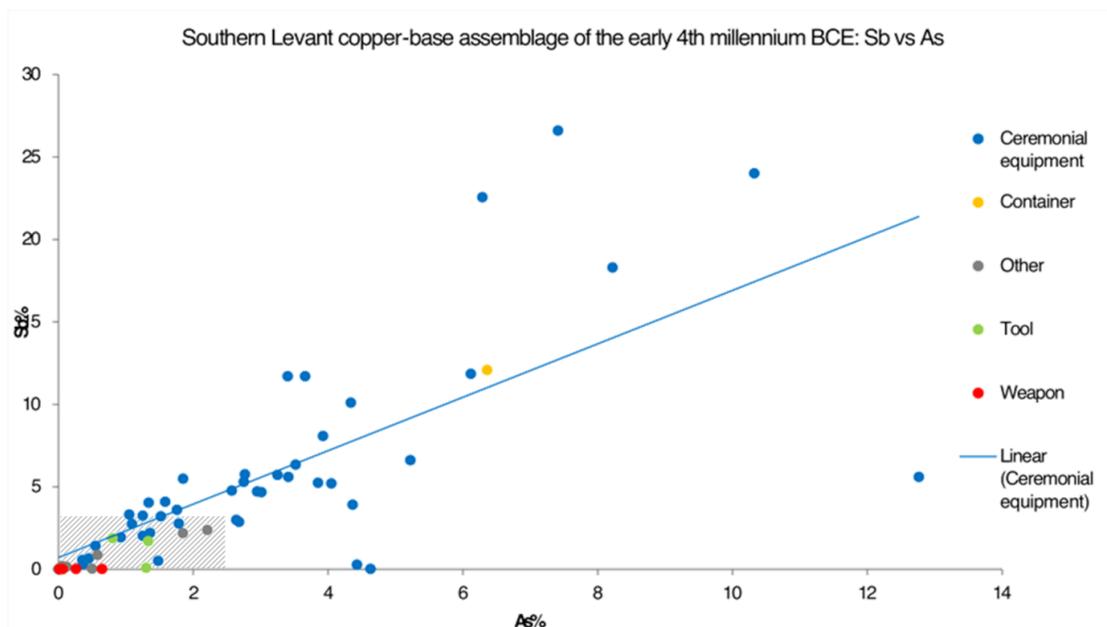


Figure 84: early 4th millennium arsenic-antimony-copper alloys from the early 4th millennium Nahal Mishmar, Giv'at Ha Oranim, Timna, Nahal Zeelim, Faynan and Shiqmim, split by typology and charted by arsenic and antimony content (excluding 'unidentified' objects from Wadi Fidan)

Thornton *et al.* (2009) and Rehren *et al.* (2012) have made a case for the practice of adding iron-arsenide speiss to produce arsenical-copper in Iran, which could be considered as a technique for achieving the high contents of arsenic or antimony in these objects from the Southern Levant. However the positive correlation of

arsenic and antimony may suggest that these two elements originated from the same source or material.

Thornton *et al.* (2009, pp.308–9) highlight the difference between ferrous speiss and base-metal speiss. The former is usually a mixture of iron-arsenide and arsenical-iron, whereas the latter can be a mixture of copper, nickel, iron and/or silver, with arsenides and antimonides. As archaeological examples of ferrous speiss seem to predominantly contain arsenic, it does not appear to have been used in the production of the arsenic-antimony-copper alloys in the Southern Levant. Antimony base-metal speiss on the other hand could have been used. In fact Thornton *et al.* (2009, p.309) go so far as to say that the copper-base objects with high antimony content from the early 4th millennium hoards are themselves border-line antimony speiss. However this revelation brings us back to square one: how were such levels of antimony achieved, and where could the ores have originated? It is also worth mentioning that evidence for iron-arsenide speiss has only been found at archaeological sites in Iran (Thornton *et al.* 2009; Rehren *et al.* 2012). This could either indicate the origin of these objects, or potentially rule out the use of speiss in their production.

Another technique to produce copper with such high antimony content is the addition of metallic antimony to a naturally arsenic-rich copper, but again one might expect to see less positive correlation between arsenic and antimony or less variable antimony contents. However it was achieved, the antimony content in these objects is unusually high and there are no ore sources in the vicinity which could have produced such an alloy. Nor is there any indication as to their region of origin, since no other region has any similar contemporaneous objects. Metallic

antimony is not found in the Southern Caucasus for another two millennia, and high antimony-copper alloys do not occur until the 3rd millennium BCE (Pike 2002).

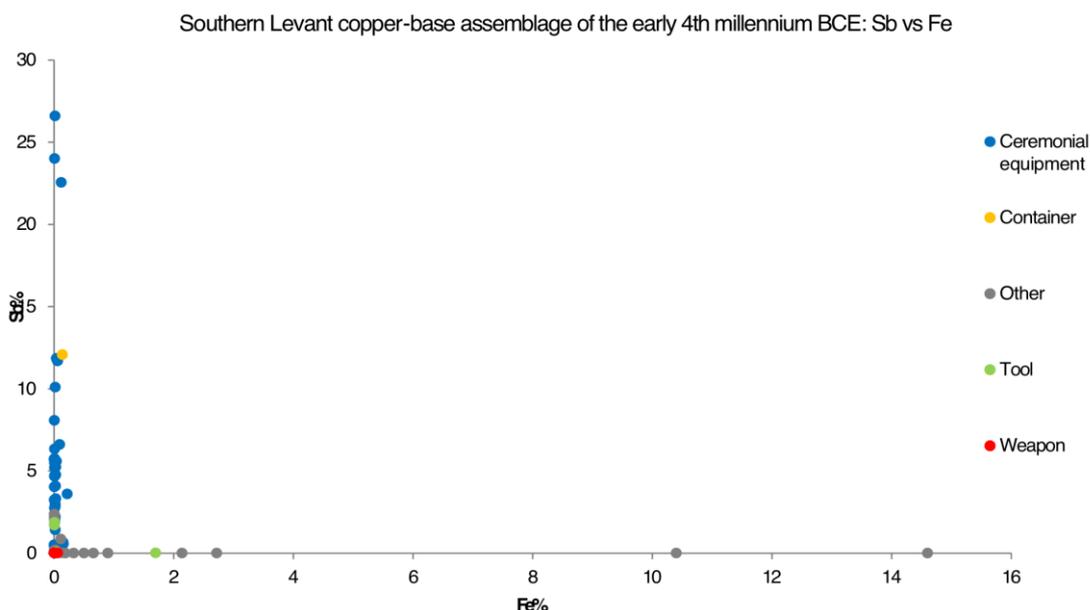


Figure 85: early 4th millennium arsenic-antimony-copper alloys from the early 4th millennium: Nahal Mishmar, Giv'at Ha Oranim, Timna, Nahal Zeelim, Faynan and Shiqmim, split by typology and charted by iron and antimony content (excluding 'unidentified' objects from Wadi Fidan)

Only one other contemporary antimonial-bronze object has been found – a cast piece from Tel Halaf in Northern Mesopotamia containing 1.1% Sb (Krause 2003). In addition to an antimony content at the lower end of the spectrum compared to the objects we are concerned with in the Southern Levant assemblage, the Northern Mesopotamian object also contains 7.38% Fe. When the antimony and iron contents of the Southern Levant assemblage are compared with one another there is a complete separation between the elements (Figure 85). This separation is also visible by object type – no ceremonial object, container, or weapon contains iron; iron is only found in one tool and several unidentified objects. The cast piece

from Tel Halaf, though containing antimony, does not therefore appear to originate from the same type of mineral or technological tradition as those from the Southern Levant.

There is only one object containing >1% Ag in Southwest Asia from the early 4th millennium BCE, and again it was found at Giv'at Ha Oranim in the Southern Levant (Namdar *et al.* 2004). This copper-alloy (containing 1.1% Ag) is one of the maceheads with high antimony content (26%) and high arsenic content (7.4%). The other elements present are lead (0.4%) and nickel (0.23%). This chemical composition could suggest that the metal was smelted from a polymetallic deposit.

As well as these extraordinary complex alloys, two of the twenty-one tin-bronze objects from early 4th millennium BCE Southwest Asia were discovered at Giv'at Ha Oranim: a pin and an axe. The axe contains perceptible levels of tin (4.9% Sn), and the pin imperceptible levels (3.89% Sn). The presence of these two additional rare and exotic alloys (there are no tin deposits in the Southern Levant) further indicates the search for extraordinary material in the Southern Levant at this time.

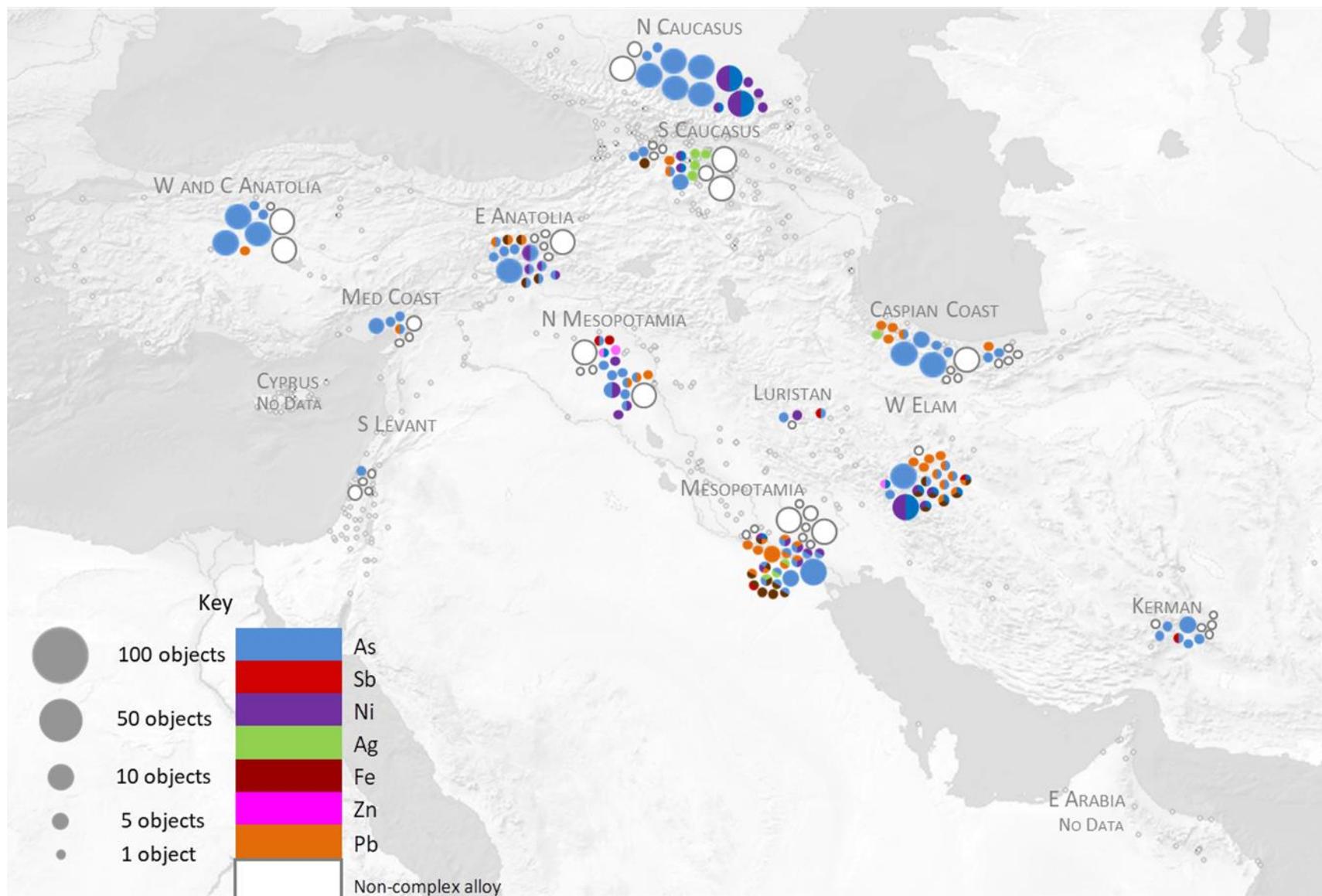


Figure 86: mid and late 4th millennium BCE regional copper-base assemblages indicating alloying elements in use (alloying elements considered as >1% As, Sb, Ni, Ag, Fe, Zn, Pb, and 'unalloyed copper')

3 Culture Expansions of the late 4th and early 3rd millennium BCE

As the Uruk Phenomenon spanned both the mid-4th and late 4th millennium BCE, and the assemblages of both chronological periods are present in either one or other of the periods, the mid-4th millennium and late 4th millennium copper-base object data have been combined into one map (Figure 86). The aim is to attempt to ascertain the flow of copper and alloying traditions across a period of intense inter-regional contact containing three extensive cultures; the Uruk Phenomenon, Kura-Araxes Culture (Early Transcaucasian Culture when outside the Southern Caucasus), and Maikop. During the mid- and late 4th millennium BCE the Mesopotamian copper-base assemblage clearly shows similarities in alloying tradition with the assemblages from Western Elam and Eastern Anatolia, with which regions it is known that Uruk Mesopotamia was in close contact (Greenberg and Palumbi 2015, p.112). It is possible however that metals were also imported from the Southern Caucasus or the Caspian Sea Coast, either directly or indirectly depending on the perceived borders of Uruk reach. The similarities between these assemblages are based on the very small quantities of copper-silver alloy objects. The use of copper-lead alloys was predominantly an eastern tradition, and arsenical-bronze a north-western tradition. Both traditions are found in Mesopotamia during this period.

In keeping with Uruk Mesopotamia's known quest for the metals and resources it was lacking, the Mesopotamian copper-assemblage during this period contains a full-range of copper-alloys which is not present in any other region. The regional

alloying traditions therefore reflect what is known of the period: that copper was imported into Mesopotamia from various neighbouring regions. This variety in alloy use decreased after the collapse of the Uruk Phenomenon in the early 3rd millennium BCE, reflecting the narrowing of trading interests which were consequently focused mainly towards the east. However this eastern focus is not reflected in patterns of alloy use between Iranian regions and Mesopotamia (Figure 124).

Chernykh (2017a; 2017b) sees the distribution of copper-arsenic-nickel and copper-nickel as evidence of communication between the Maikop Culture of the Northern Caucasus and Eastern Anatolia, going so far as to draw parallels between the Maikop Kurgans and the Royal Burial of Arslantepe. However, from Figure 86 and Figure 87 the main period of use of nickel-bearing copper alloys in both regions do not correlate, and by the time they are predominant in Eastern Anatolia the Maikop Culture had collapsed. In the late 4th millennium BCE there was an adoption of arsenic-nickel-copper in Susa, Western Elam, alongside the small assemblages in Eastern Anatolia, Northern Mesopotamia, and Mesopotamia. This pattern indicates links with the Uruk Phenomenon rather than with Maikop, as Maikop metallurgists were not exploiting Northern Caucasian copper deposits and Susa was a “virtual extension” of Southern Mesopotamia during the late 4th millennium BCE (T. F. Potts 1993, 382). If arsenic-nickel copper originated in the Southern Caucasus, on the other hand, this could be an indication that Uruk presence did reach further than the Iranian and Anatolian highlands and as far as the Southern Caucasus as put forward by Akhundov (2014).

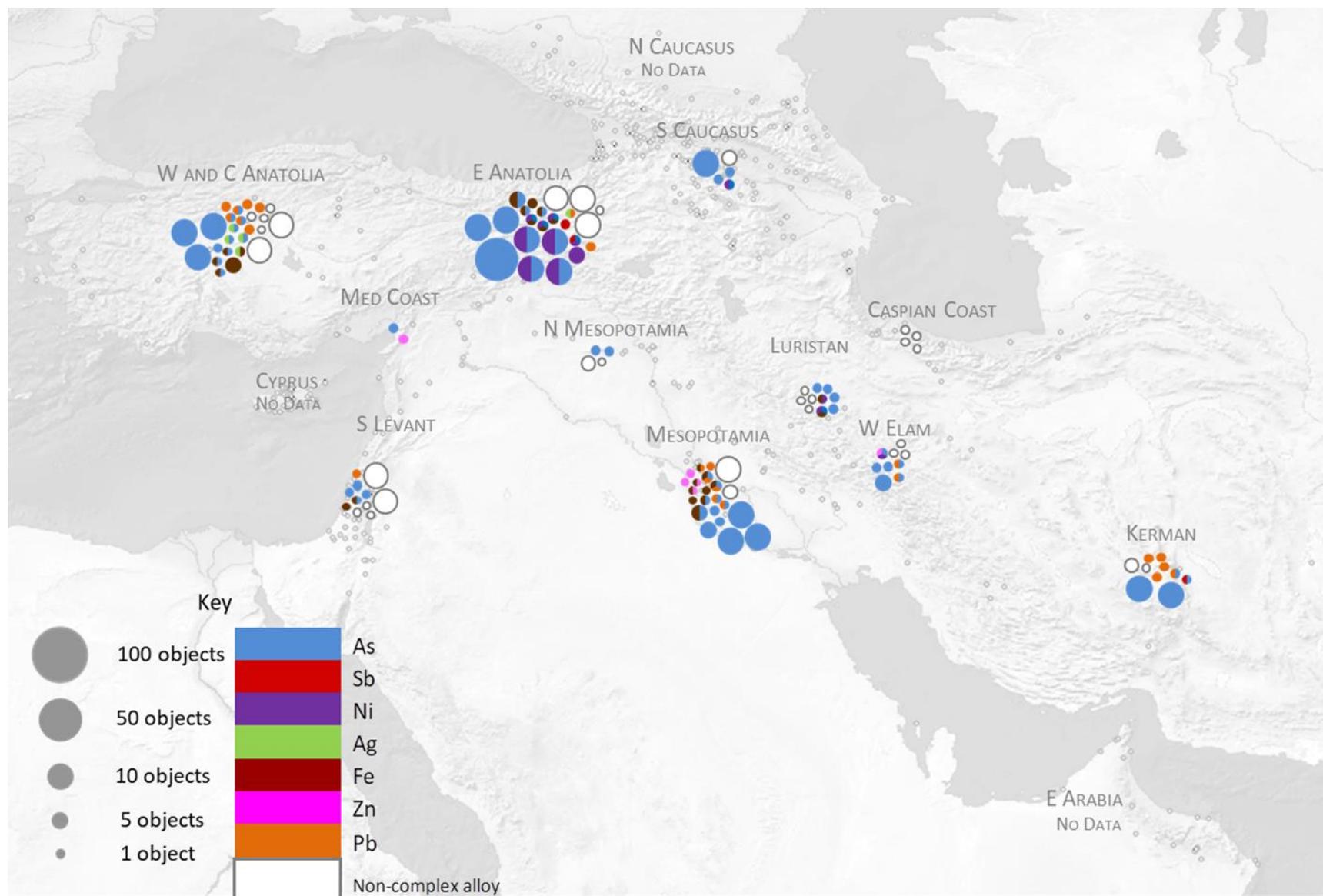


Figure 87: early 3rd millennium BCE regional copper-base assemblages indicating alloying elements in use (alloying elements considered as >1% As, Sb, Ni, Ag, Fe, Zn, Pb, and 'unalloyed copper')

On the other hand, extended patterns of nickel-bearing copper alloy use also coincide with the Kura-Araxes Culture and later expansion. Though in the late 4th millennium BCE Maikop burials produce an extraordinary number of copper and other metal objects, but there are no indications of metalworking or ore exploitation. Chernykh had also previously stated that Maikop copper could have been sourced and exported north by the Kura-Araxes Culture in the Southern Caucasus and Eastern Anatolia (Chernykh 2017a, p.480). It could therefore possibly a consequence of the spread of Kura-Araxes into Eastern Anatolia that is responsible for the signal of arsenic-nickel-copper alloy.

From the late 4th millennium BCE to the early 3rd millennium BCE, the Kura-Araxes (or Early Transcaucasian Culture) was expanding, reaching the southern border of Eastern Anatolia c. 3000 BCE, Iran c. 2900 BCE, and the Southern Levant c. 2800 BCE (Rothman 2015). Arsenic-nickel-copper use increases dramatically in Eastern Anatolia from c. 2900/3000 BCE, possibly representing the transmission of the copper-alloy with the spread of the Early Transcaucasian Culture as to Northern Caucasian assemblages in the previous period.

The presence of arsenic-nickel-copper in the Northern Caucasus and Eastern Anatolia could suggest a direct connection between Anatolia and Maikop as outlined by Chernykh. On the other hand, the movement of the alloy to Eastern Anatolia chronologically could indicate the spread of the Kura-Araxes/Early Transcaucasian Culture. Figure 88 depicts the nickel content of all copper-base objects containing >0.1% Ni from the Northern Caucasus in the late 4th millennium BCE and from Eastern Anatolia in the early 3rd millennium BCE in an attempt to understand this mystery further. In both the Eastern Anatolian and Northern

Caucasus assemblages the nickel contents have an extremely similar pattern, with the majority of objects containing between 0.15 and 2% Ni, although there are two peaks of nickel content at 3.5% and 4.5% in the Northern Caucasus assemblage. This similarity could indicate a shared source for the material but does not rule out the Southern Caucasus as a source since there is no similar data with which to compare it.

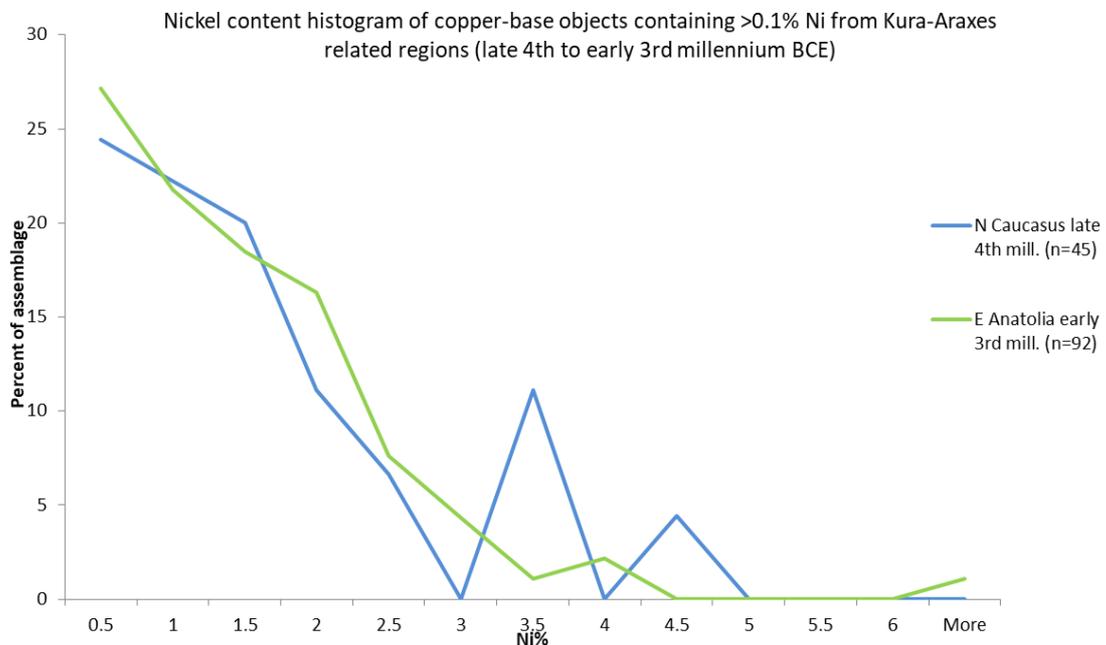


Figure 88: Histogram of nickel content in copper-base assemblages from Kura-Araxes related regions (late 4th millennium Northern Caucasus and 3rd millennium Eastern Anatolia), objects included if they contain >0.1% Ni.

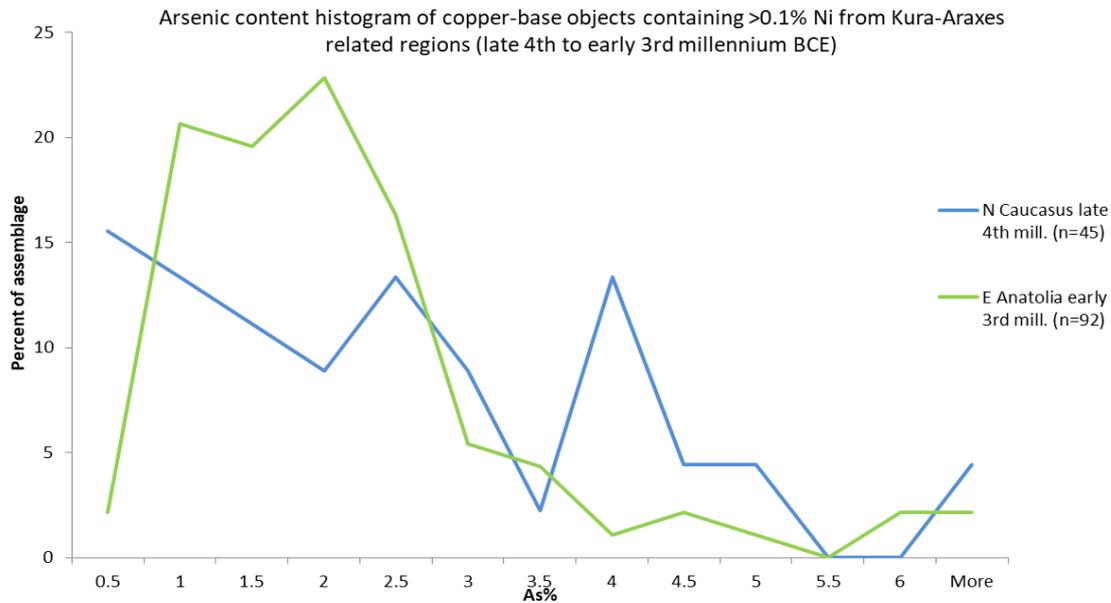


Figure 89: Histogram of arsenic content in copper-base assemblages from Kura-Araxes related regions (late 4th millennium Northern Caucasus and 3rd millennium Eastern Anatolia), objects included if they contain >0.1% Ni.

Figure 89 represents the same assemblages but depicts arsenic contents instead of nickel. Despite having a similar nickel content distribution as the Northern Caucasus, the arsenic contents are generally lower in the Eastern Anatolian assemblage. This could be indicative of re-melted and re-worked copper-arsenic-nickel, as nickel contents remain stable while there is a contemporaneous loss of arsenic. If the source of arsenic-nickel-copper was to be found in Eastern Anatolia, we would surely expect to see higher arsenic concentrations in that assemblage. Despite lacking any analytical assemblages that indicate their use, does this therefore represent copper-arsenic-nickel objects being transported by Kura-Araxes migrants from the Southern Caucasus to Eastern Anatolia? Or does it simply represent isolated use of different nickeliferous ores with varying amount of arsenic present from both Eastern Anatolia and the Northern Caucasus? If the latter it is possible that the alloy represents the transmission of knowledge, which would indicate Kura-Araxes, as the Maikop Culture had no metallurgical tradition.

Unfortunately neither Iran nor the Northern Levant (other regions into which Kura-Araxes culture was adopted) have sufficiently large assemblages at the time of the ETC expansion to meaningfully add to the discussion.

4 Mid-3rd millennium BCE antimonial-bronze as an indication of isolation

From c. 2700 BCE flourishing trade across Southwest Asia reappears (Liverani 2014, p.93; Frahm and Feinberg 2013, p.1868; Matney 2012, p.563), and is reflected in the increase of copper-based objects in all regions (Figure 90). It is in this period that Mesopotamia's main access to copper is via the Persian Gulf from Magan (T. F. Potts 1993). The distinctive high nickel composition of Omani copper, however, is not yet visible in the Mesopotamian assemblage. Written evidence from Lagash suggests that at this time only relatively small amounts of finished copper were imported into Mesopotamia (Edens 1992, p.126). On the other hand, arsenic-nickel-copper *is* present at Susa, possibly indicating an unequal distribution of the early Persian Gulf trade. It is possible that participation in the Gulf trade was not only up the Persian Gulf but across it and via land: there are known links between Southwest Iran and Eastern Arabia, represented in the soft-stone vessels and black-on-grey painted ware found at Tepe Yahya, on the Jiroft Plain, in Baluchistan, and at Susa during the second half of the 3rd millennium BCE (Potts 2003; Potts 2005; D. T. Potts 1993). However there is no corresponding use

of arsenic-nickel-copper in those regions east of the Persian Gulf. There are instances of arsenic-nickel copper use along the Euphrates and Tigris River routes into West and Central Anatolia and the Southern Caucasus, possibly indicating trade between Western Elam and the Euphrates Valley. Equally the presence of arsenic-nickel-copper in these regions may be a continuation of the Maikop or Kura-Araxes traditions of the late 4th millennium BCE as discussed above.

After the collapse of the Early Transcaucasian Culture, the Northern and Southern Caucasus went through a period of isolation from Southwest Asia (Chernykh 2017a). This isolation is visible in the predominance of zinc-rich copper (>1% Zn), antimonial-bronze and (to a lesser extent) silver-copper alloy, which is not common in any other region. The only other region which also contains some examples of zinc-rich copper and silver-copper alloy is Mesopotamia, perhaps indicating continued contact between the Caucasus and Mesopotamia, or remnants of trade from earlier periods. It is important to remember, however, that the Southern Caucasus assemblage at this time is very broadly dated within the 3rd millennium BCE and could therefore be unreliable, possibly representing the use of alloys in the adjacent chronological periods.

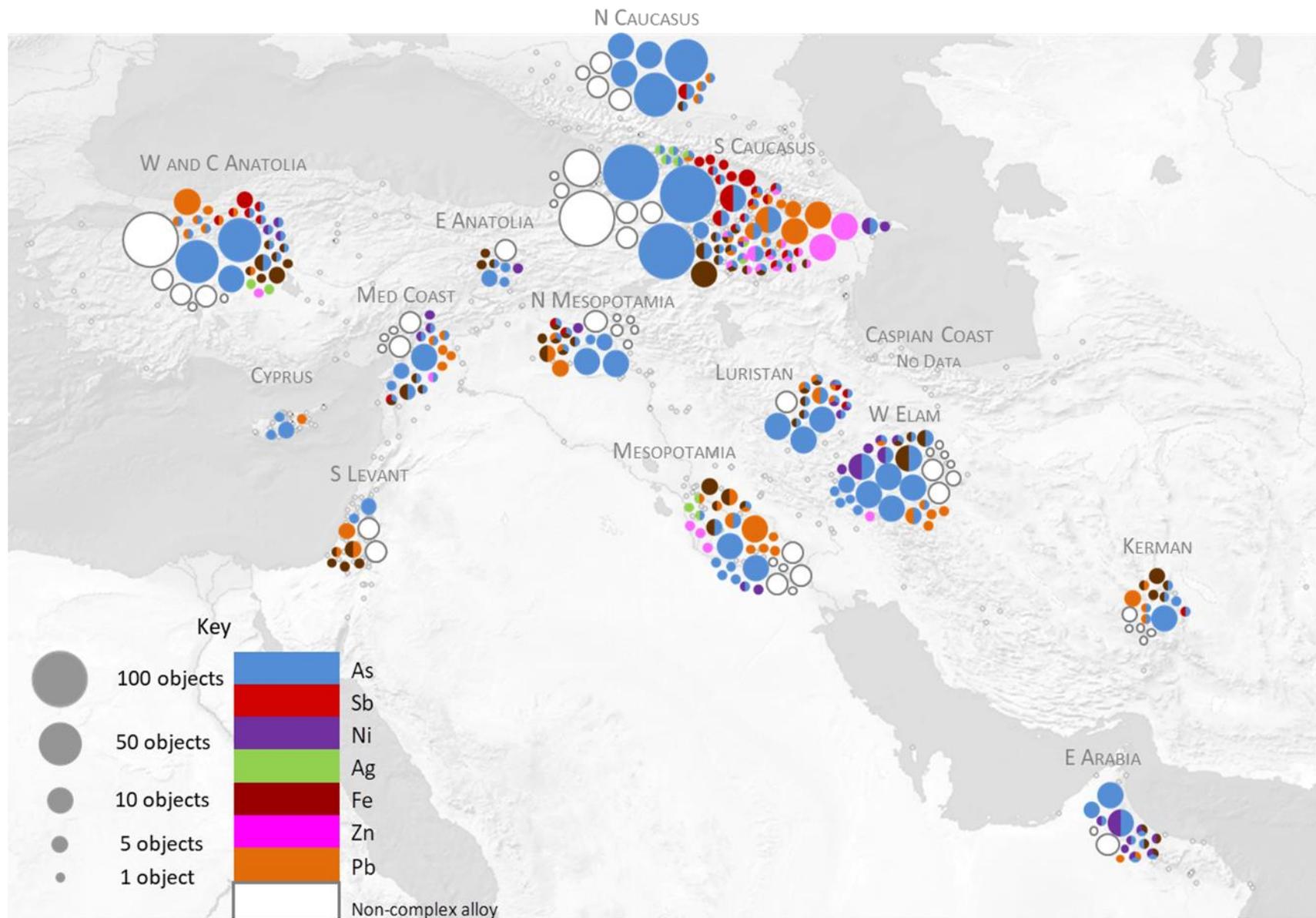


Figure 90: mid-3rd millennium BCE regional copper-base assemblages indicating alloying elements in use (alloying elements considered as >1% As, Sb, Ni, Ag, Fe, Zn, Pb, and 'unalloyed copper')

The sudden increase in antimonial-bronze in the Southern Caucasus, and its use in the Northern Caucasus and West and Central Anatolia could indicate links between the Caucasus and parts of Anatolia despite signs of isolation. Figure 91 plots the antimony and arsenic contents of objects from the three regions which contain >0.1% Sb. The diagram shows a similarity in the range of antimony in the assemblages, but a lower arsenic level in West and Central Anatolian copper. The lower arsenic level could indicate the use of more frequently recycled or re-melted copper in Anatolia, as antimony does not deplete at the same rate as arsenic. However it could also indicate use of copper ores and copper-alloys unconnected to the Caucasus at this time.

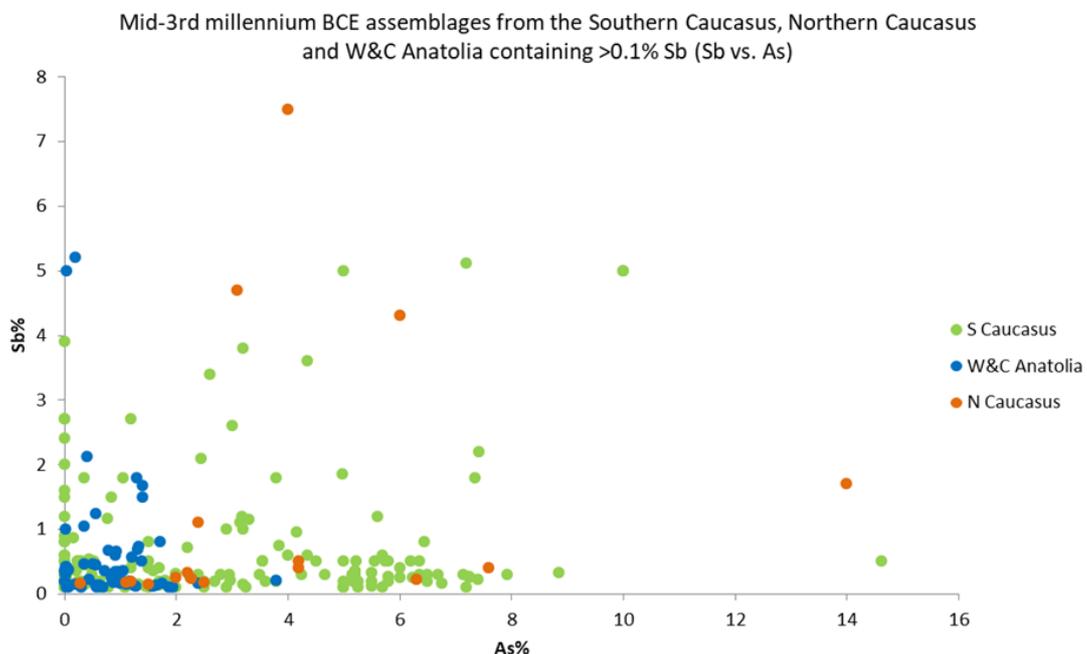


Figure 91: Arsenic and antimony contents of objects from mid-3rd millennium BCE Southern Caucasus, Northern Caucasus, and West and Central Anatolia

5 3rd millennium tin-bronze use and what it says about Kestel

This section will address regional tin-bronze traditions relating to the duration of the 3rd millennium BCE in Southwest Asia. It is during the 3rd millennium that the main period of exploitation under question was occurring at the Kestel mine. Despite lack of certainty over the material exploited during that time, contemporary tin-bronze use from Southwest Asia, with a focus along the Euphrates and Tigris River routes, will be considered in an attempt to understand whether Kestel's status as *the* tin source is a feasible theory. If it was, we should expect to see certain patterns of tin-use. To establish whether it was anything more than a local tin mine, the larger regions nearest the mine might be expected to have sustained a stable and flourishing tin-bronze industry. To establish direction of trade, tin content of tin-bronzes along the hypothesized trade route will be examined; in this instance a decrease in tin content along the route might establish direction of travel. The tin-route suggested by Yener and Vandiver (1993, p.209) crosses Cilicia and the Mediterranean Coast, from where it would presumably have joined and followed the Euphrates River and continued down to Mesopotamia.

At the start of the 3rd millennium BCE there was a slight increase in tin-bronze use in Northern Mesopotamia, Luristan, and the Caspian Sea Coastal region compared to the pattern of tin-bronze use in the preceding period, but it was minimal (Figure 92). The tin-bronze industry of Southwest Asia as a whole in the early 3rd millennium BCE was little more than a collection of stray and isolated finds except for at Demircihüyük (West and Central Anatolia) and Kalleh Nissar (Luristan). In

West and Central Anatolia sixteen of the seventy-eight objects found are made of tin-bronze, most containing between 6.5% and 33% Sn (Massa *et al.* 2017; Begemann *et al.* 2003; Gale *et al.* 1985; Kunç 1986). As the pattern for tin-bronze use in the rest of Southwest Asia does not support the widespread importation of tin or tin-bronze objects at this time it seems likely that West and Central Anatolian craftspeople were exploiting a local tin-source. The import of tin from the Western Mediterranean or the Balkans is another possibility, but one outside the scope of this thesis. If an Anatolian tin-source was in use, it seems a reasonable assumption that it could have been at a location such as Kestel, Hisarcik, Madenköy, or Madenbelenitepe deposits (Yener *et al.* 2015; Begemann *et al.* 2003; Öztürk and Hanilci 2009).

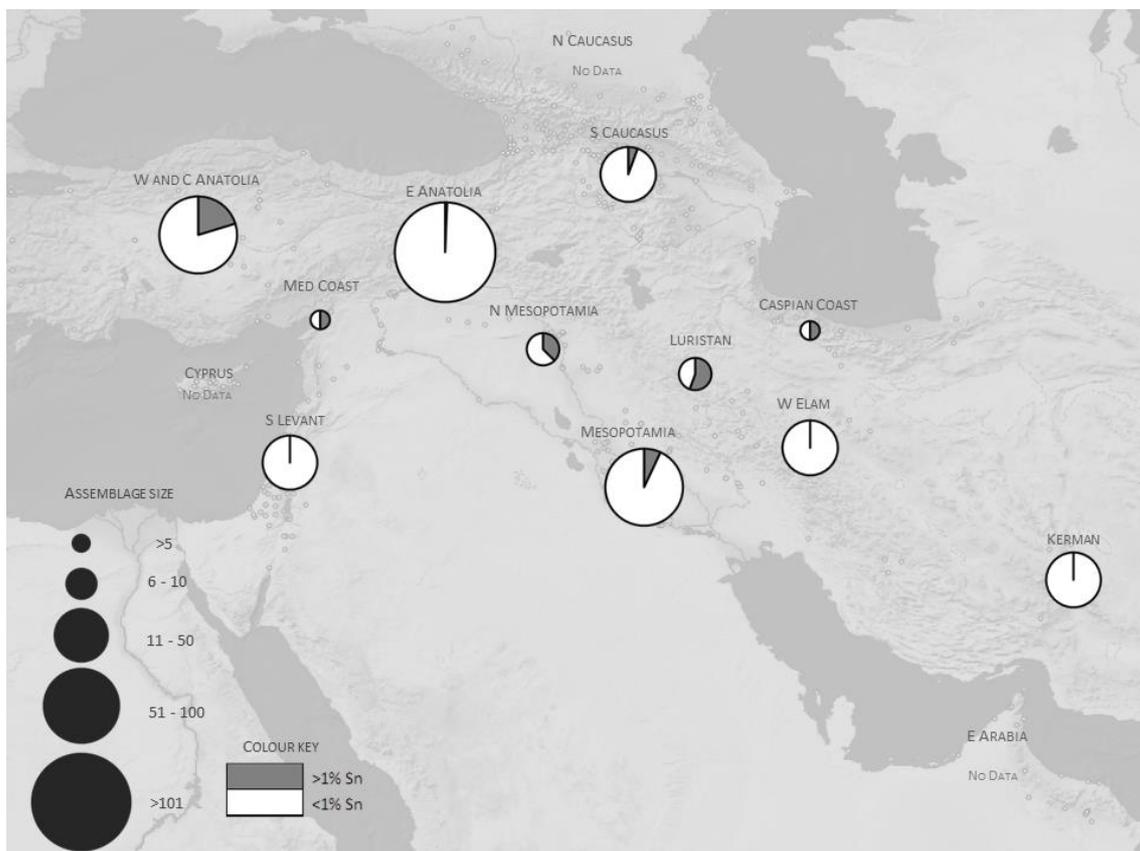


Figure 92: early 3rd millennium BCE percent of assemblage containing >1% Sn (grey) against objects containing <1% Sn (white)

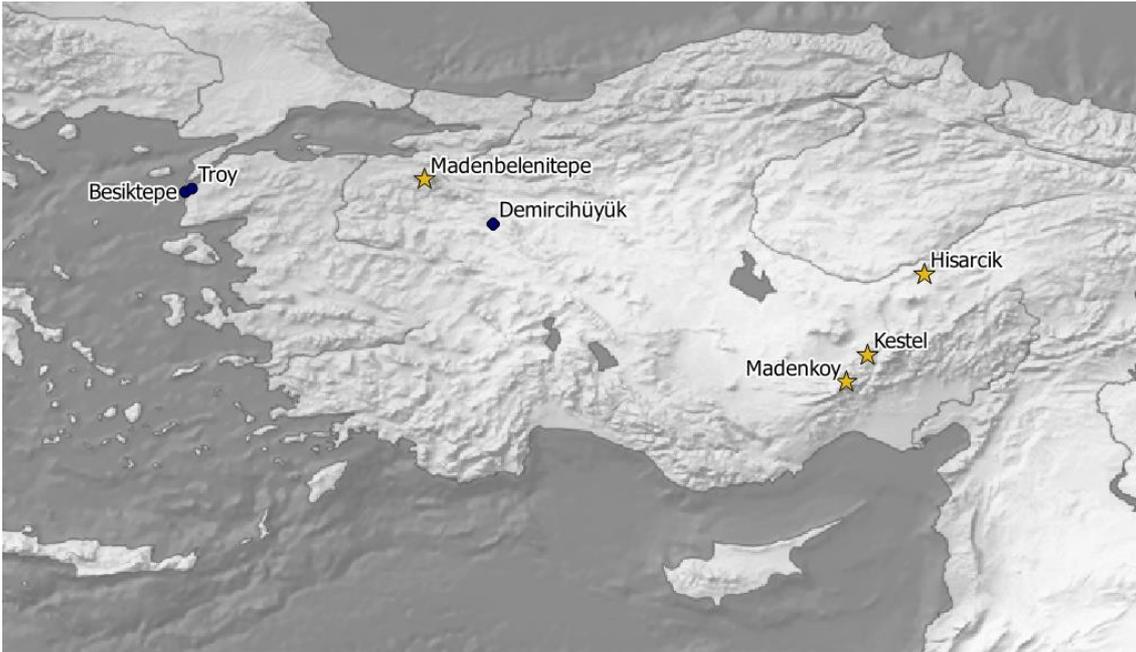


Figure 93: location of early 3rd millennium BCE sites containing tin-bronze objects from West and Central Anatolia

Figure 93 shows the location of all sites for which tin-bronze data has been collected in West and Central Anatolia (the only other site with analysed metal from this period is Ikiztepe in the Black Sea region), and Table 26 lists the objects by site, object type and trace elements. Troy, Besiktepe, and Demircihüyük are all located at a significant distance from the Kestel mine, and are located closer to the Bursa Province, also documented to have tin deposits (Begemann *et al.* 2003). One might expect a burgeoning tin industry to occur near the locally available necessary raw materials. On the other hand the metal assemblage at Demircihüyük is extraordinary: with 188 copper, 37 lead, 44 gold, and 17 silver objects. The inhabitants of this site could have been involved in elite gift exchange and long-distance trade (Massa *et al.* 2017, p.53).

Table 26: early 3rd millennium BCE tin-bronze objects from W&C Anatolia. N.B. “-” indicates no figure provided by analysts or authors, “0” indicates not detected or not present, objects highlighted in blue indicate alloying levels of additional elements, grey: >0.1% of impurity element.

Provenance	Object	Sn	As	Fe	Pb	Ni	Sb	Ag	Zn
Troy	Ring	12.50	0.09	0.03		0.04	0.02	0.01	0.04
Besiktepe	Pin	9.20	0.09	0.02		0.02	0.02	0.03	0.00
Besiktepe	Chain	11.50	0.33	0.05		0.08	0.13	0.08	0.02
Demircihüyük	Pin	6.50	0.57	0.23	0.17	0.10	0.10	0.10	0.20
Demircihüyük	Pin	7.48	0.05	0.20	0.10	0.10	0.10	0.05	0.20
Demircihüyük	Pin	7.48	0.05	0.20	0.10	0.10	0.10	0.05	0.20
Demircihüyük	Mace	11.50	0.10	0.37	0.72	0.10	0.12	0.05	0.25
Demircihüyük	Mace	11.50	0.05	0.37	0.72	0.10	0.12	0.05	0.25
Demircihüyük	Mace	13.18	0.52	0.34	8.52	0.05	0.12	0.05	0.20
Demircihüyük	Mace	13.18	0.52	0.34	8.52	0.10	0.12	0.10	0.20
Demircihüyük	Spear	15.50	0.36	0.18	5.04	0.10	0.10	0.10	0.20
Demircihüyük	Spear	15.50	0.36	0.18	5.04	0.05	0.10	0.10	0.20
Demircihüyük	Pin	18.25	1.15	0.65	0.68	0.10	0.30	0.10	0.20
Demircihüyük	Dagger	29.58	1.18	0.30	0.33	0.18	0.35	0.20	0.20
Demircihüyük	Pin	34.33	3.63	0.50	4.90	0.10	0.50	0.13	0.20

Some of the tin-bronzes are also quite varied complex alloys: there is one arsenic-lead-tin alloy, two arsenic-tin copper alloys, and four leaded-tin-bronzes. Also unusual in comparison with the general trend of copper-base objects from Southwest Asia (as reflected in this database), there are traces of gold in *all* Demircihüyük copper-base objects, something which is not reflected at contemporary Besiktepe or Troy, or indeed often witnessed at all. However it is possible that this is a result of the analytical technique applied, as all determined trace elements are recorded at >0.1 apart from bismuth, which wavers from 0.05 – 0.1%, a situation unique to this set of objects.

All tin-bronze objects (>1% Sn) in West and Central Anatolia in the early 3rd millennium BCE, contain >5% tin, the level at which tin-bronze is perceptibly different from copper (Kuijpers 2017). This is not the case in the contemporary tin-bronze assemblages from the rest of Southwest Asia. Only five of nineteen tin-bronze objects contain >5% Sn: three objects from Mesopotamia; a mirror (8.9% Sn), and two vessels (13.9% and 18.3% Sn); a vessel from Luristan (5.8% Sn); and

a pin from Northern Mesopotamia (10.3% Sn). All other objects contain between 1 and 3.85% Sn and a great variety of impurities, though to some extent these impurities are also present in the tin-bronzes containing >5% Sn (Table 27). This does indicate that there was a slight difference in technological tradition between West and Central Anatolia and the rest of Southwest Asia and implies a regional experience of manufacturing objects with this particular material.

Table 27: early 3rd millennium BCE tin-bronze objects from Southwest Asia not including W&C Anatolia. N.B. “-” indicates no figure provided by analysts or authors, “0” indicates not detected or not present, objects highlighted in gold indicate those with perceptible levels of tin, grey: >0.1% of impurity element)

Provenance	Larger Area	Object	Sn	As	Fe	Pb	Ni	Sb	Ag	Zn
Tall as-Sulaima	Mesopotamia	Spearhead	1.05	0.89	0.001	1.94	0.13	0.2	0.08	0.001
Tepecik	E Anatolia	Unidentified	1.2	0.005	0.07	0.005		0.44		0.005
Mersin	Med Coast	Bracelet	1.29	0.33	0.51	0.37	0.04	0.04	0.09	17.75
Tall Razuk	Mesopotamia	Bifide point	1.29	1.66	0.57	0.06	0.02	0.07	0.11	0.001
Tepe Gaura	N Mesopotamia	Unidentified	1.33	1.34	0.14	0.53	0.64	0.15	0.14	0.001
		Axe-head	1.55	1.55		0.03	0.23	0.07	0.02	
Tepe Hissar	Caspian Coast	Ring/bracelet	1.74		0.001	0.65				
		Band	2.06		0.001	0.35				
Agarak	S Caucasus	Awl	3	0.087	0.045	0.52	0.047	0.018	0.039	0.05
Kalleh Nisar	Luristan	Pin	2.73	0.57	0.41	0.093	0.497	0.008	0.017	0.001
		Bracelet	3.49	1.07	0.39	0.76	0.14			
		Pin	3.74	0.91	0.45	0.18	0.72			
		Bracelet	3.85	0.69	0.15	0.19	0.62			
		Vessel	5.8	0.507	0.195	0.033	0.033	0.008	0.045	0.005
Tepe Gaura	N Mesopotamia	Pin	10.3	0.67	0.18	0.06	0.34	0.001	0.001	0.001
Tello		Vessel	13.9	0.37	0.83	0.03	0.39	0.001	0.001	0.001
Kis	Mesopotamia	Mirror	8.9	0.52	0.11	0.71	0.06	0.02	0.02	0.001
		Vessel	18.3	0.07	1.77	0.001	0.02	0.001	0.001	3.6

Figure 94 shows the first real Southwest Asia wide adoption of tin-bronze, though it is mainly the regions along the Euphrates which demonstrate any stability of tin use. The Southern Caucasus assemblage contains a large number of tin-bronze objects at this time, however all the tin-bronze objects are only broadly dated to the 3rd millennium BCE, so must be treated with caution.

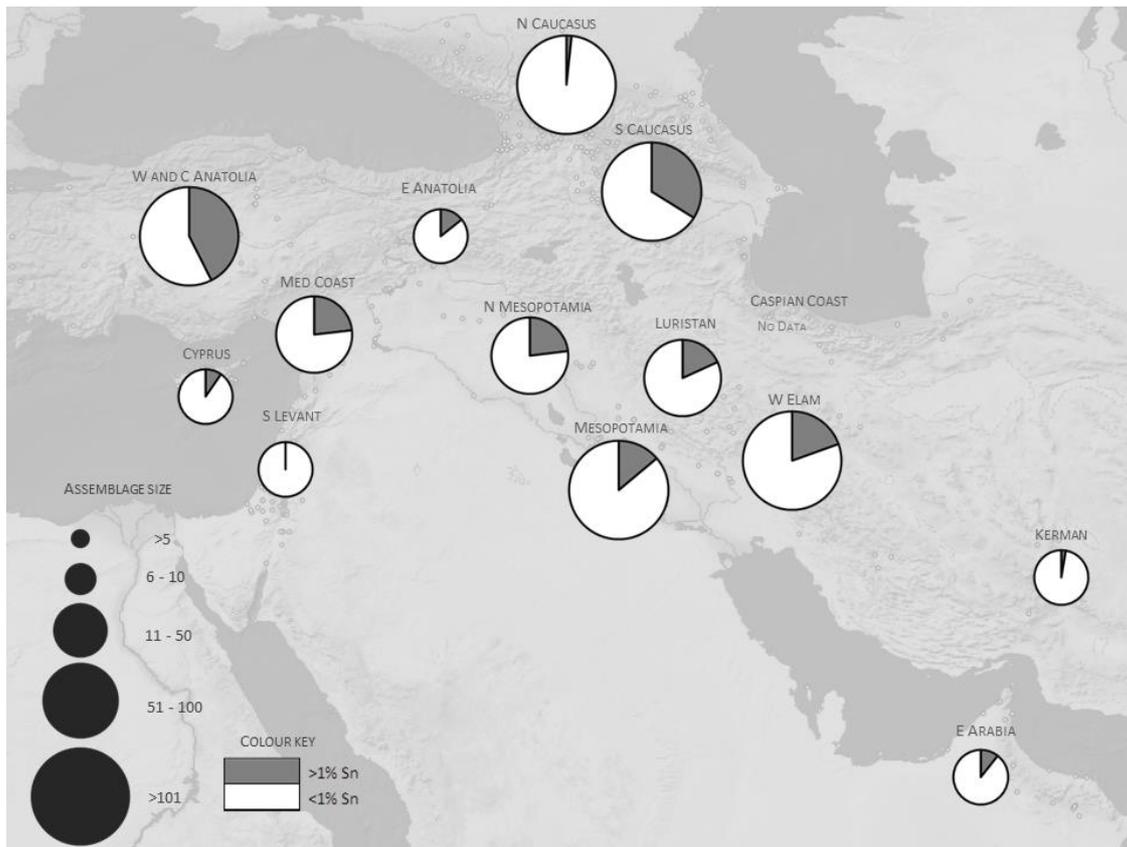


Figure 94: Mid-3rd millennium BCE percent of assemblage containing >1% Sn (grey) against objects containing <1% Sn (white)

Figure 95 depicts the percentage of each regional copper-base assemblage containing >1% tin, and which is ordered from the largest to smallest percentage (this does not represent actual numbers). The regions bordering the hypothesized trade route from Kestel to Mesopotamia are marked with an asterisk. It is hypothesised that the further a region is from the tin-rich area, the lower the regional tin-bronze use will be. The case of mid-3rd millennium tin-bronze use could be suggestive of tin traded in a southeast direction, and therefore support the theory that the Kestel tin-mine supplied Mesopotamia. The presence of three tin-bronzes on Cyprus found at Vasilia on the northern coast could therefore also reflect the short-lived century of contact with the Mediterranean Coast region of Anatolia (c. 2400 BCE) and potentially be tin from Kestel.

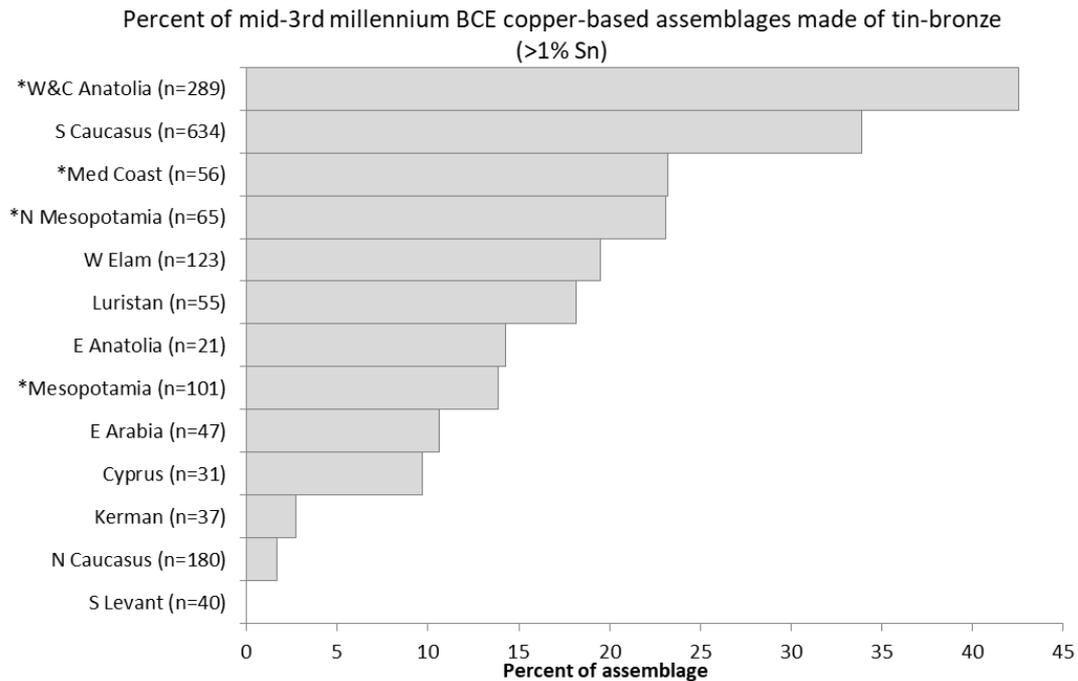


Figure 95: Chart depicting percent of each regional copper-base assemblage containing >1% Sn from the mid-3rd millennium BCE. N. B. * = region located along hypothesised trade route from Kestel to Mesopotamia)

Figure 96 shows the site locations of tin-bronze objects found along the hypothesized trade route (Cyprus and Eastern Anatolia are also included owing to proximity and therefore possibility of their location along alternative trade routes). The tin content of each object is reflected in the shade of the dot – lighter dots indicate lower tin content, darker indicates higher. The highest tin contents are found in Mesopotamia, not near Kestel. In fact the closer to Kestel the objects are, the lower the average tin content. The objects from Göltepe, the proposed processing site, contain either <5% Sn or between ~11 or 12% Sn. The four objects from the Mediterranean region contain 1.75 to 5.2% Sn (Yener 2000; Yener and Vandiver 1993; Laughlin and Todd 2000).

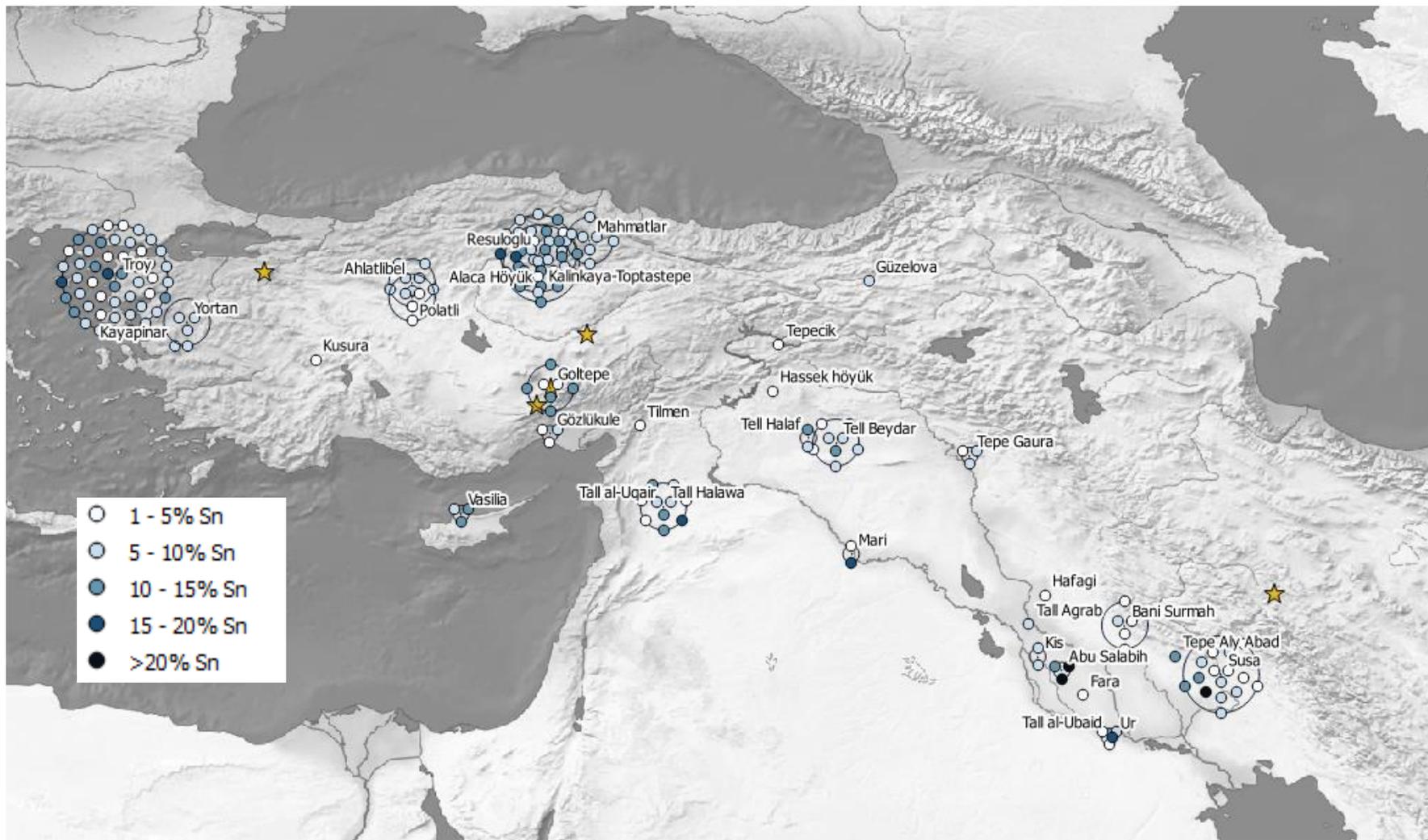


Figure 96: Map depicting individual tin-bronze objects and their tin content from the mid-3rd millennium BCE specified sites along the hypothesised tin trade route from Anatolia to Southern Mesopotamia and Western Elam

The tin-bronze assemblages from Southern Mesopotamia and Western Elam on the other hand contain three objects containing >15% Sn, and several containing 10 – 20% Sn. This suggests that the flow of direction was away from Mesopotamia up to Anatolia, especially if the tin content of scattered tin-bronzes in the Upper Euphrates/Syro-Anatolia region is also considered. It is possible that the tin was traded to Mesopotamia in ingot-form, and therefore that the Mesopotamian metalsmiths were able to include a higher tin content to their copper-base assemblage than was attempted in Göltepe. However, we would still expect to see higher and more frequent tin use in the intervening regions, as craftspeople would surely also have had access to this supply unless Göltepe is considered an extension of Mesopotamia itself, with all produced tin earmarked for Mesopotamian cities.

The sites Tell Halawa and Tall al-Uquair in the Northern Levant (Mediterranean Coast) show the most similarity to the Göltepe assemblage, and trade could possibly have occurred southeast following the Mediterranean Coast before being transported across Syria and joining the Euphrates later at Mari. However Tell Halawa and Tall al-Uquair could also indicate trade coming via the Mediterranean Sea. The region around Troy had a very strong tin-bronze tradition at this time, and whichever source was supplying that region could also have gone on to supply the Eastern Mediterranean. Another region with the most consistent and frequently high tin contents is the Black Sea, though presumably trade would have to have travelled along the Euphrates or Tigris before it could reach Mesopotamia.

The pattern of tin-bronze does not overwhelmingly indicate trade from Kestel to the rest of Southwest Asia. The objects from Göltepe *do* support a small-scale local-

level exploitation, and tin-bronze use in the Black Sea region (Alaç Höyük, Resoğlu, Mahmatlar, etc.) could also indicate a region wide industry. However the Mediterranean Coast pattern of tin-bronze use is indicative of a region at the end of a trade route, not at the beginning, suggesting that if tin from Kestel was in use it only travelled north of the Taurus.

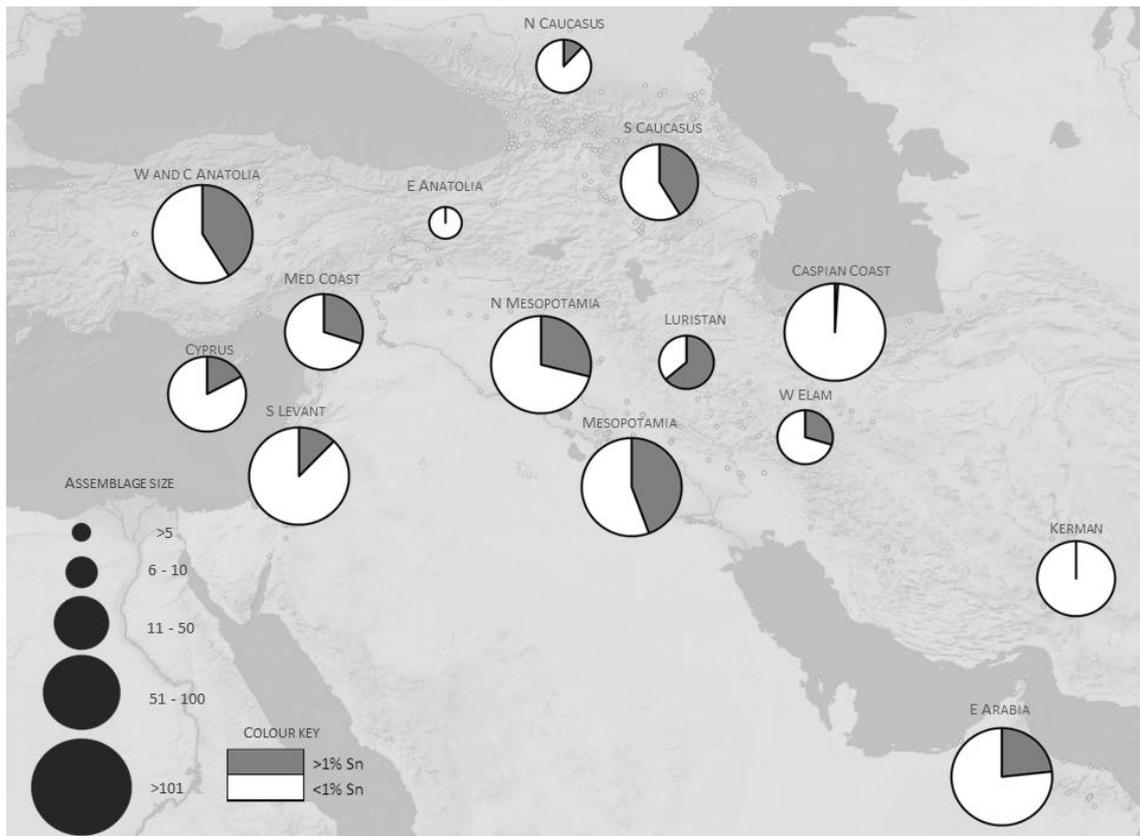


Figure 97: Late 3rd millennium BCE percent of assemblage containing >1% Sn (grey) against objects containing <1% Sn (white)

In the late 3rd millennium BCE there was a much more regionally varied approach towards the tin-bronze industry, with regional inequality in tin acquisition becoming more evident (Figure 97). This change in pattern could indicate a transition in technological tradition or possibly trading practice. After a shared pan-regional industrial development or access to a new resource had been widely established, certain regions may have developed individual traditions or secured

avenues of acquisition, affecting the abundance of tin-bronze use between regions. For instance, West and Central Anatolia, Mesopotamia, Northern Caucasus, and Luristan appear to have been importing large amounts of tin and so could have been actively seeking trade in the material. Alternatively Eastern Anatolia, the Southern Levant, Kerman, and the Caspian Coast appear either not to have sought the material or had no access to it.

Large-scale exploitation and export of tin from Kestel has not been demonstrated thus far by patterns of tin-bronze use in neighbouring regions. Local use and perhaps northbound trade from Kestel have not been ruled out. Figure 98 shows a map of all tin-bronze objects in Southwest Asia, though the assemblage from Ur is represented separately in a histogram owing to the overwhelming number of artefacts. From the tin content displayed in the tin-bronzes from West and Central Anatolia, the similarity between object contents could definitely indicate a region supplied by Kestel. Most objects in Anatolia as a whole contain 1 - 10.4% Sn and could be consistent with regionwide access to tin from Kestel. Hisarçik should be mentioned here as most West and Central Anatolian tin-objects are in fact closer to it, though as discussed earlier, proximity is not the over-riding factor when it comes to resource choice.

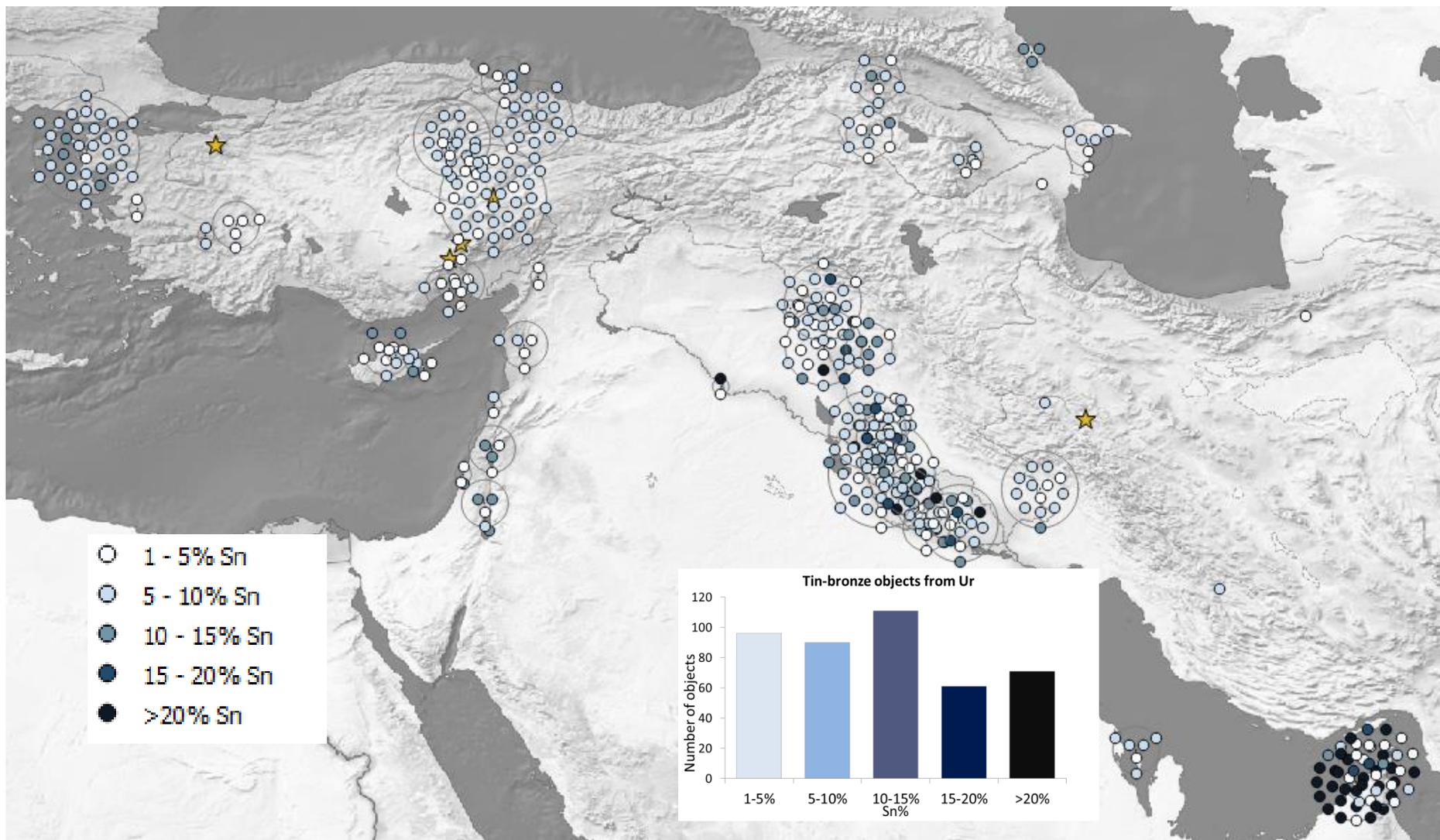


Figure 98: Map depicting individual tin-bronze objects and their tin content from late 3rd millennium BCE Southwest Asia, objects from Ur are represented as a chart owing to the large number of objects

The pattern of tin-bronze use in Mesopotamia, Western Elam, and other neighbouring regions does not support the practice of large-scale export of tin from Kestel, or anywhere else in Anatolia, to Southwest Asia. The tin is more likely to have come via Eastern Arabia, the assemblage of which contains objects with very high tin contents, only paralleled on any real scale in the Mesopotamian assemblage.

If alloying patterns are also looked at in tandem with the potential for tin supplied via the Persian Gulf, we can also see a similarity in alloy use from Eastern Arabia up to Northern Mesopotamia and the Mediterranean Coast (Figure 99). Copper-arsenic-nickel (characteristic of Magan copper), silver-copper, lead-copper, and copper with >1% iron are all present in the extended Euphrates region, suggesting shared metallurgical traditions and a copper trade which potentially accompanied the tin supply.

Tin-bronze objects from copper-base assemblages in Cyprus and the Southern Levant have the highest tin contents in the Eastern Mediterranean. It is possible that tin was traded to the Southern Levant from Egypt (Richard 2013, p.14), and shared between these regions via seafaring trade, though it does not appear to have been traded eastwards. On the other side of Southwest Asia, Kerman and the Caspian Sea Coastal region still had little or no tin-bronze use at this time, suggesting that if tin was coming from the east it was not being transported via the land route through Iran. Nor did tin appear to arrive from the north through the Caucasus, as the Northern Caucasus show very little evidence of tin-bronze use.

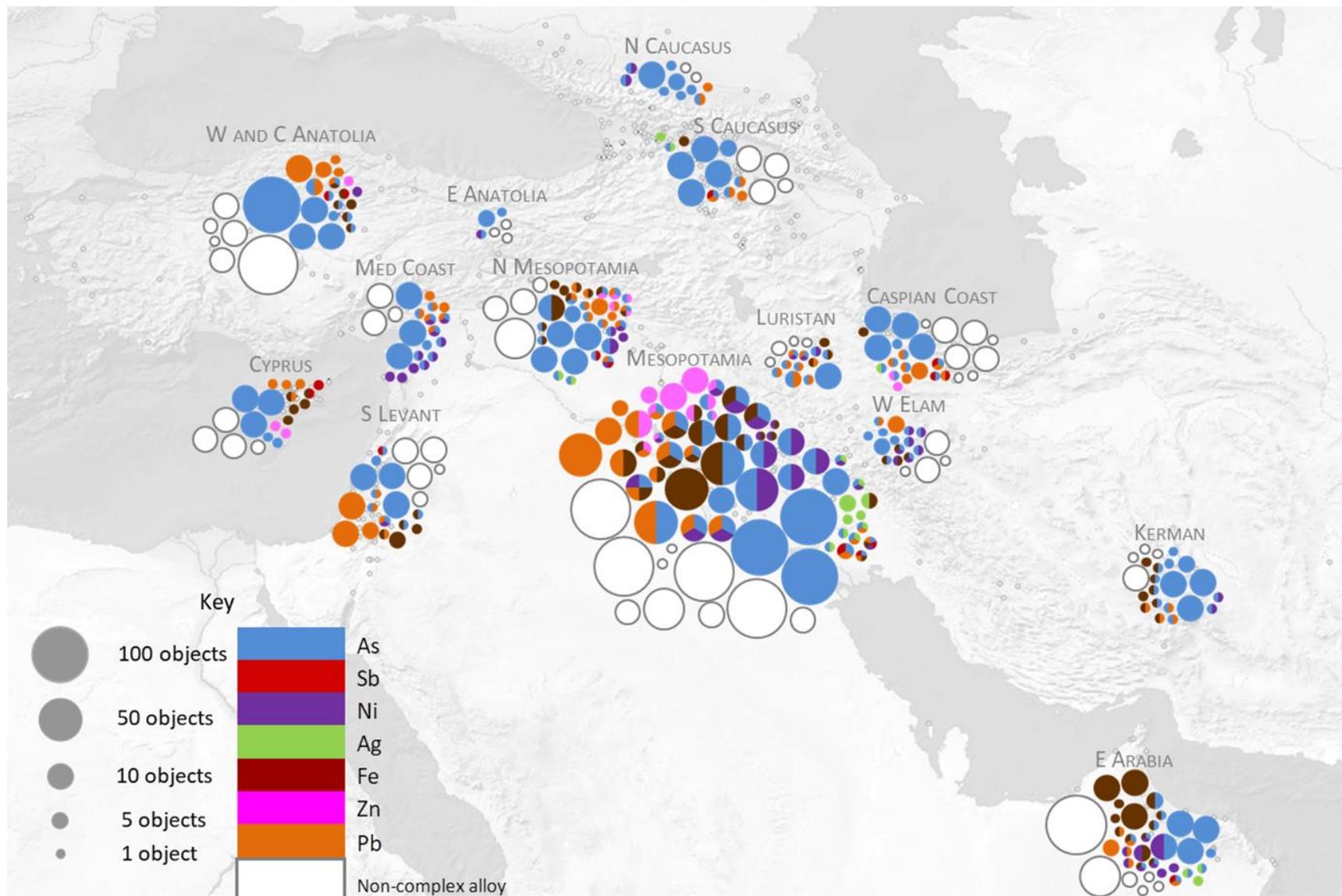


Figure 99: late 3rd millennium BCE regional copper-base assemblages indicating alloying elements in use (alloying elements considered as >1% As, Sb, Ni, Ag, Fe, Zn, Pb, and 'unalloyed copper')

6 Early 2nd to mid-2nd millennium BCE: changing copper supply

In this section the effect of the collapse of the Dilmun copper trade along the Persian Gulf and the synchronous genesis of the Cypriot copper trade on alloying traditions of Southwest Asia will be considered. Magan copper contained characteristically high levels of nickel and arsenic, whereas copper from Cyprus was arsenic-rich only. Did this disappearance of nickel in the general copper composition have any effect on copper-base alloying traditions? As the Dilmun copper trade is believed to have been synonymous with the tin trade at this time, the collapse of the route must also have had a dramatic effect on tin-bronze use, and the question of tin supply is once again at the forefront of research. Cyprus and the Levant were closely connected in the mid-2nd millennium BCE (Knapp 1986), however presumably they were also industrial rivals: the Southern Levant was a copper-producing region in its own right, and the widespread trade of Cypriot copper across Southwest Asia may have limited Southern Levantine opportunities for copper exportation. The periods under question are the early 2nd millennium and mid-2nd millennium BCE, with the aim of encompassing the entire period of change and the patterns of copper-alloy use immediately preceding the conversion of the copper supply. The late 2nd millennium BCE is also included as Cypriot copper exportation continued until the 12th c. BCE.

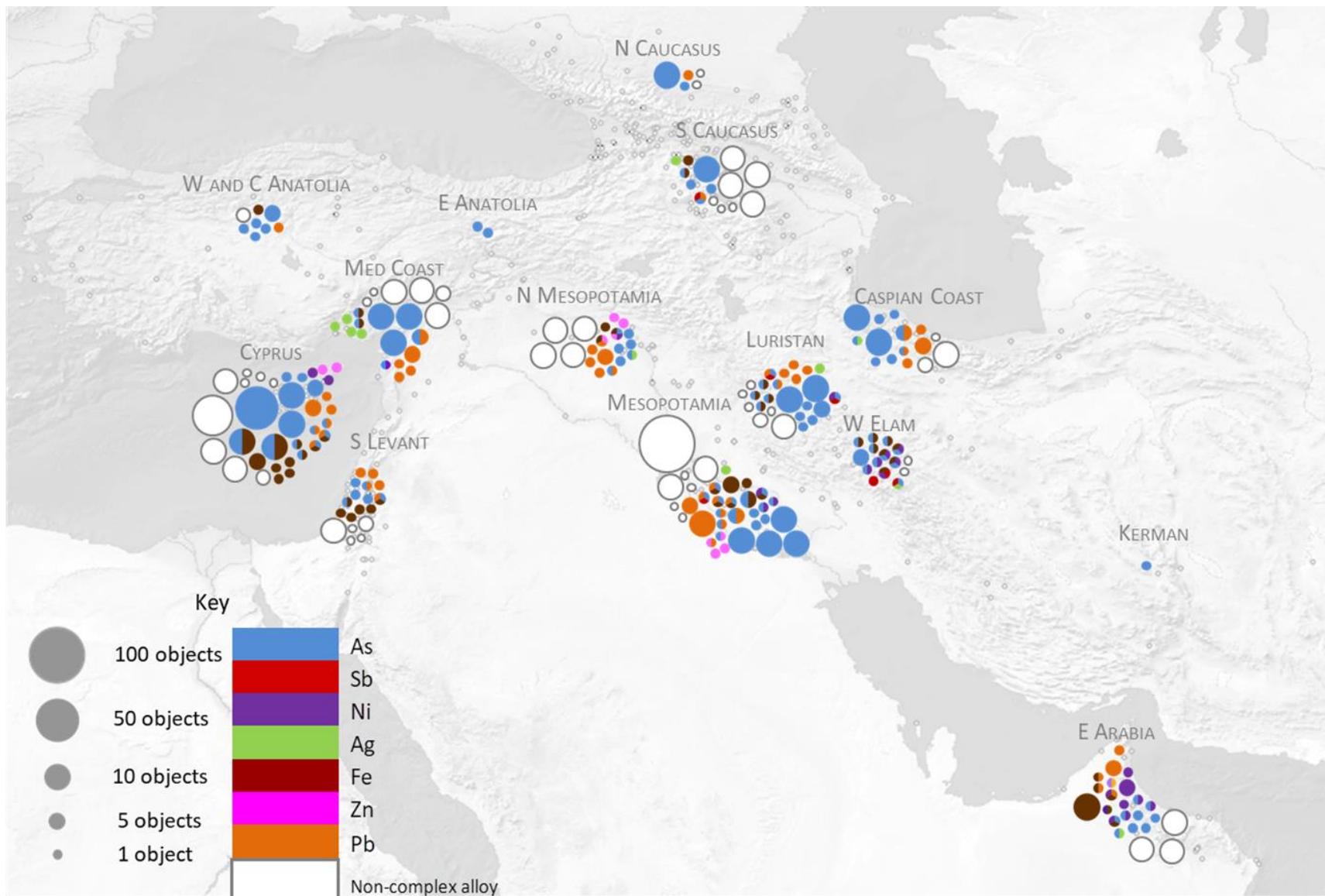


Figure 100: early 2nd millennium BCE regional copper-base assemblages indicating alloying elements in use (alloying elements considered as >1% As, Sb, Ni, Ag, Fe, Zn, Pb, and 'unalloyed copper')

In Figure 100 two things are immediately visible. Firstly, the copper containing >1% nickel in Eastern Arabia at this point is less likely to contain similarly high quantities of arsenic, as in preceding periods. This may indicate a change in smelting or refining practice, or even an increased tradition of recycling which would produce a general loss of arsenic if conducted in open crucibles. Secondly, objects containing >1% nickel are much less common across Southwest Asia at the start of the 2nd millennium BCE as they had been previously. Although the trade of Magan copper via Dilmun collapsed at the end of this period, the quantity of copper imported into Mesopotamia had not begun to decline in the early 2nd millennium: correspondence from a Mesopotamian merchant specifies “multiple shipments of Dilmun copper totalling approximately 18 tonnes” (Weeks 2007, p.89). If these quantities are correct Magan copper should be visible at least in the Mesopotamian copper assemblage, if nowhere else, but the signal of Magan copper is significant by its absence.

Figure 101 depicts the arsenic and nickel concentrations of copper in the early 2nd millennium BCE copper-base assemblages from Eastern Arabia, Mesopotamia, and Cyprus. The Eastern Arabian assemblage, though containing a depleted average arsenic content in comparison to objects from previous periods, still displays the characteristic high nickel signal with significant quantities of arsenic. The Cypriot copper-base assemblage contains high arsenic levels, but little nickel. The Mesopotamian assemblage is curiously distinct from both potential supplies – the nickel content indicates that Cypriot copper is not the source of Mesopotamian copper, but the nickel levels are also lower than those from the East Arabian assemblage. Perhaps this indicates the mixing of Cypriot and Magan copper by

Mesopotamian craftspeople, thus diluting the nickel content and increasing the arsenic, bearing in mind the loss that would occur through reheating.

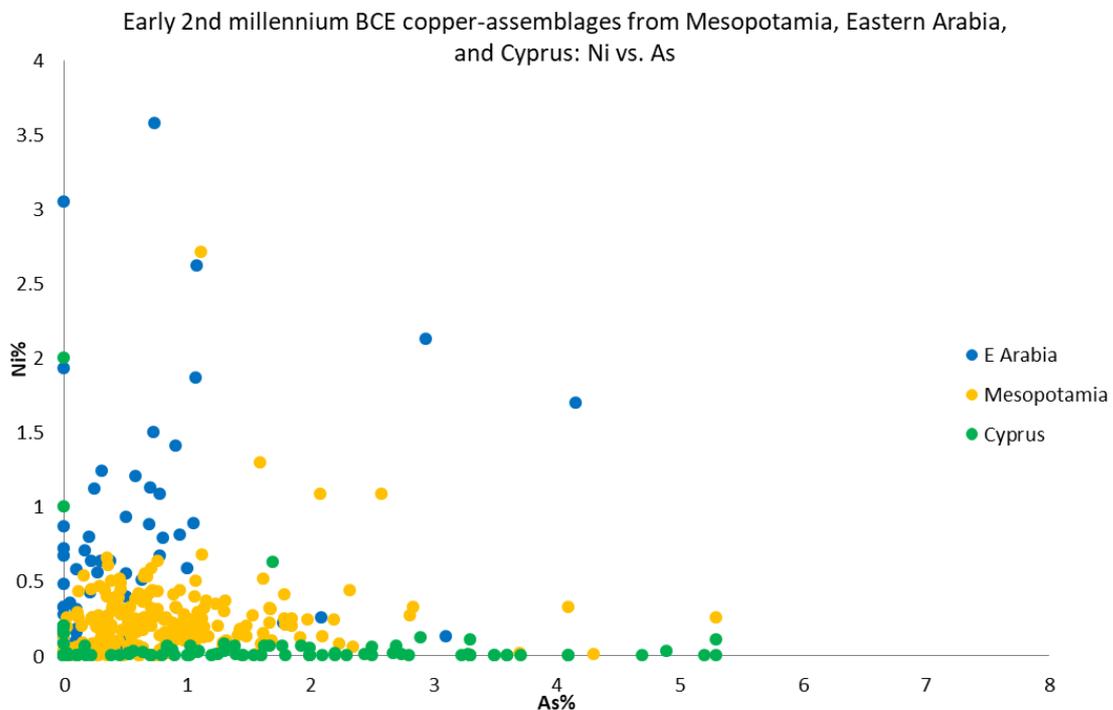


Figure 101: Nickel and antimony contents of early 2nd millennium BCE copper base assemblages from Eastern Arabia, Mesopotamia and Cyprus

Figure 102 shows an increased and shared tin-bronze tradition between the regions of the Levant, Mediterranean Coast, and Cyprus, no doubt owing to the increase in maritime trade and better connections with Southwest Asia via Mari and the copper trade.

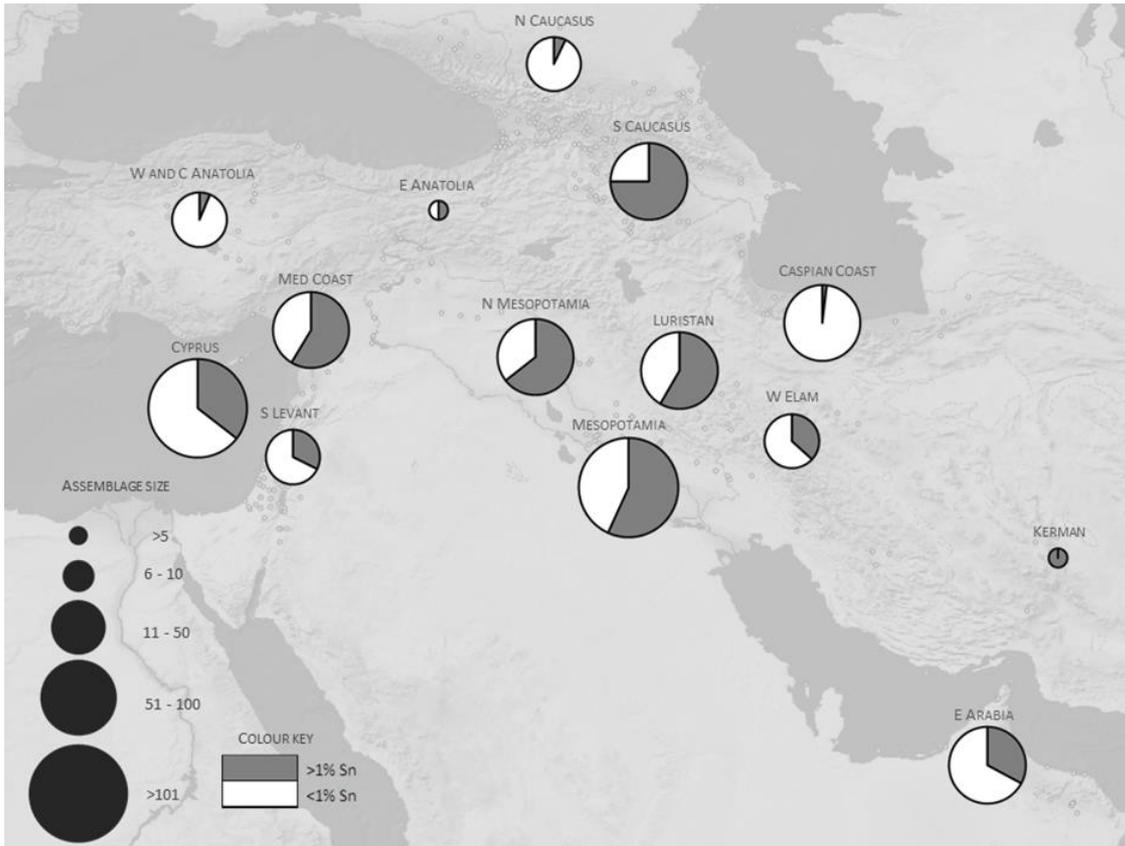


Figure 102: Early 2nd millennium BCE percent of assemblage containing >1% Sn (grey) against objects containing <1% Sn (white).

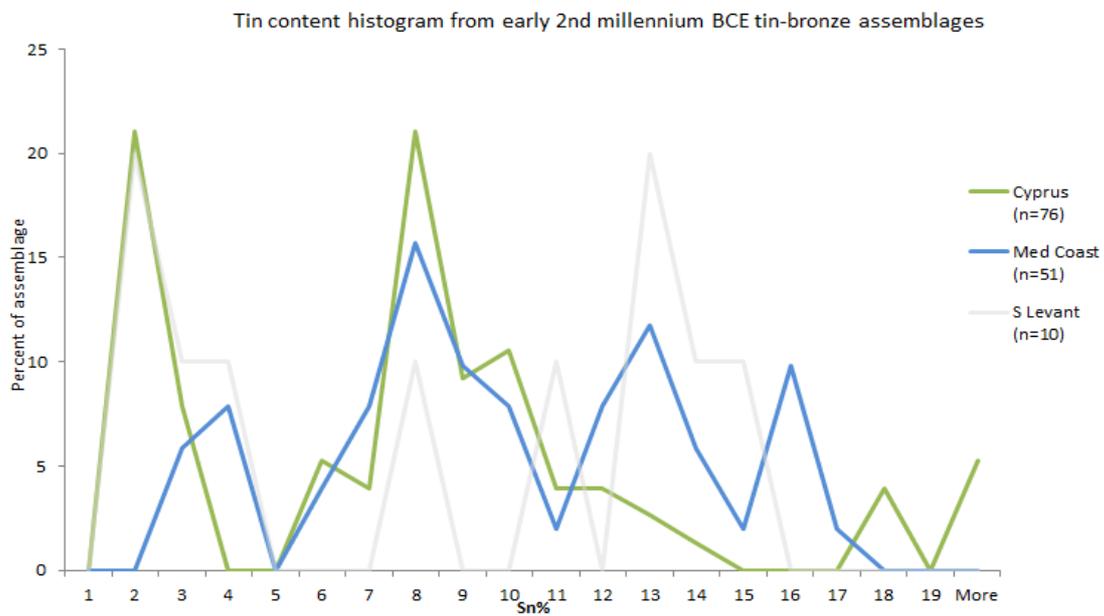


Figure 103: Histogram of tin content in the tin-bronze assemblages from early 2nd millennium BCE Cyprus, Mediterranean Coast, and the Southern Levant

Figure 103 outlines the tin content of tin-bronzes from Cyprus, the Mediterranean Coast, and the Southern Levant (the latter of which is depicted in grey owing to the low sample size). If tin was now being imported from the western Mediterranean rather than Southwest Asia, we might expect to see the same peak across all regions, as access to tin ingots (the presence of which have been established by finds on the Ulu Burun and Cape Gelidonya shipwrecks) would ensure metallic tin to all coastal regions, though not necessarily in equal quantities. The benefit of metallic tin in stabilising alloying traditions is that the final tin content of the resultant material is more easily controllable. However the tin content is frequently higher in the Mediterranean Coast assemblage than in the Cypriot assemblage, suggesting that at this time tin was still arriving from the east at the Mediterranean Coast and being transported on to Cyprus. The similar tin-bronze traditions from the Mediterranean Coast and Cyprus, and their known maritime contact (Knapp 1986), indicate a technological cohesion, possibly owing to the transmission of developments and a consistent influx of tin.

The Caspian Sea Coastal and Kerman regions still lacked significant tin-bronze use in the early 2nd millennium BCE. There was apparently no connection between the region and the Southern Caucasus along the Caspian Sea coast, as the Southern Caucasus still had a very strong tin-bronze tradition, continuous since the mid-3rd millennium BCE. In addition to the lack of tin-bronze use along the Caspian Sea Coast, the slight increase in Eastern Arabian tin-bronze use suggests that tin was still traded via the Persian Gulf at least as far as Eastern Arabia.

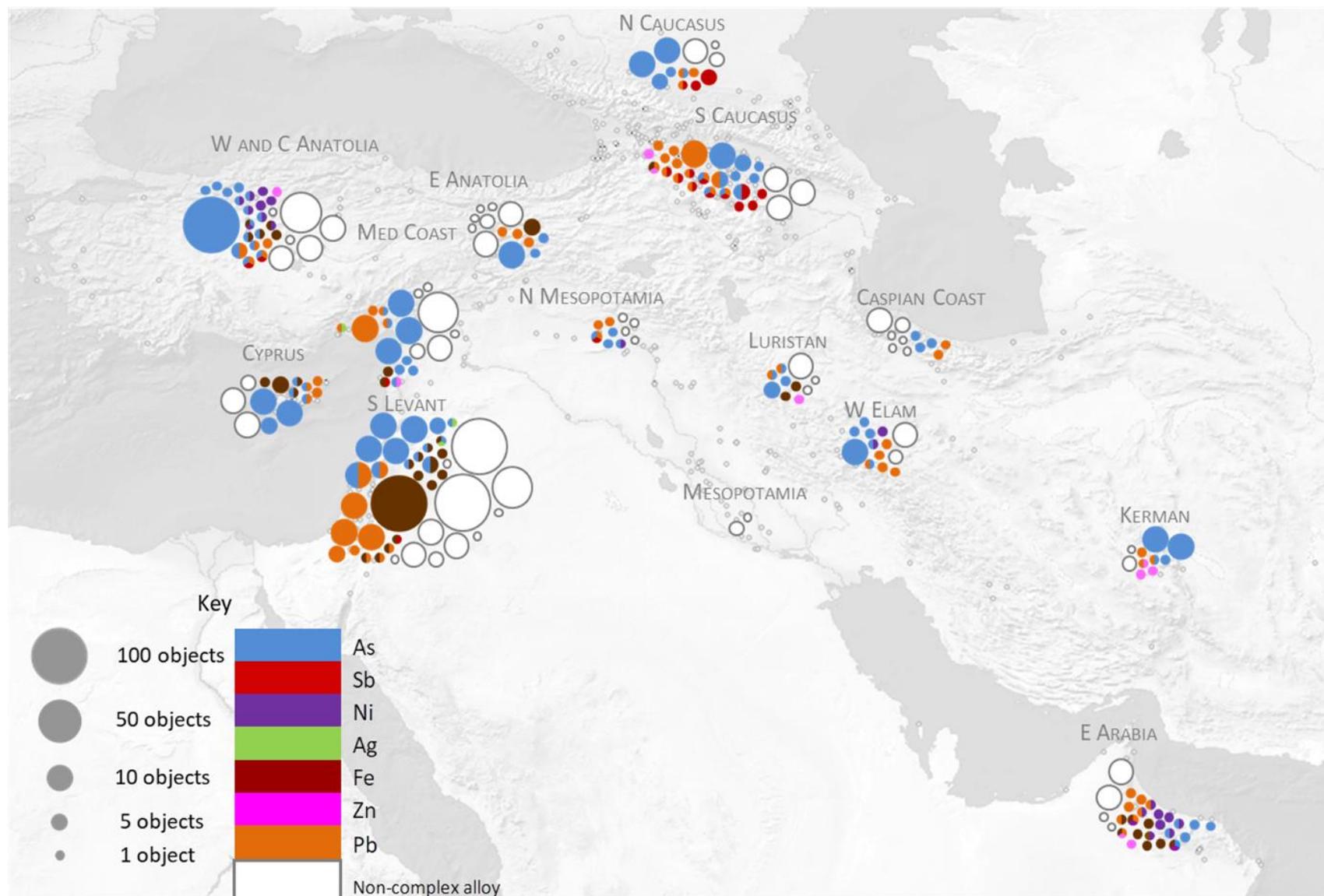


Figure 104: mid-2nd millennium BCE regional copper-base assemblages indicating alloying elements in use (alloying elements considered as >1% As, Sb, Ni, Ag, Fe, Zn, Pb, and 'unalloyed copper')

In the mid-2nd millennium BCE, the period, during which Cypriot copper exports were flourishing, the complex trading network which spread across Southwest Asia was both neutral to political conflict and structurally organised to distribute rare materials monopolized by certain regions (Knapp 1986, p.45). Perhaps as a direct consequence the alloying traditions became relatively homogeneous across the mainland (Figure 104). Pure copper, copper-lead, copper-iron, and arsenic-copper are the main alloys represented in Cyprus, the Southern Levant, the Mediterranean Coast, Eastern Anatolia, Western Elam, and Kerman. The Southern Caucasus assemblage also looks similar, but with the significant regionally specific addition of antimony-copper.

Eastern Arabia's lack of contact with the rest of Southwest Asia is evident in its isolated nickel alloying traditions and relative lack of arsenic-copper alloy. As mentioned previously the disruption of the export of copper from Magan c. 1750 BCE would probably have impacted the import of tin to Southwest Asia. It is difficult to ascertain the consequent effect on the mid-2nd millennium BCE tin-bronze industry because the analytical assemblages of the regions that would most easily reflect this change (Mesopotamia and Northern Mesopotamia) are severely depleted at this time. There is one very visible change, however: tin-bronze was adopted in the Caspian Coast region and Kerman for the first time since the beginning of the Metal Age (Figure 105). This could surely be an indication that once trade along the Persian Gulf was no longer viable tin had to be transported overland through the centre of modern Iran, thus allowing acquisition of tin in areas which had previously been deprived of it.

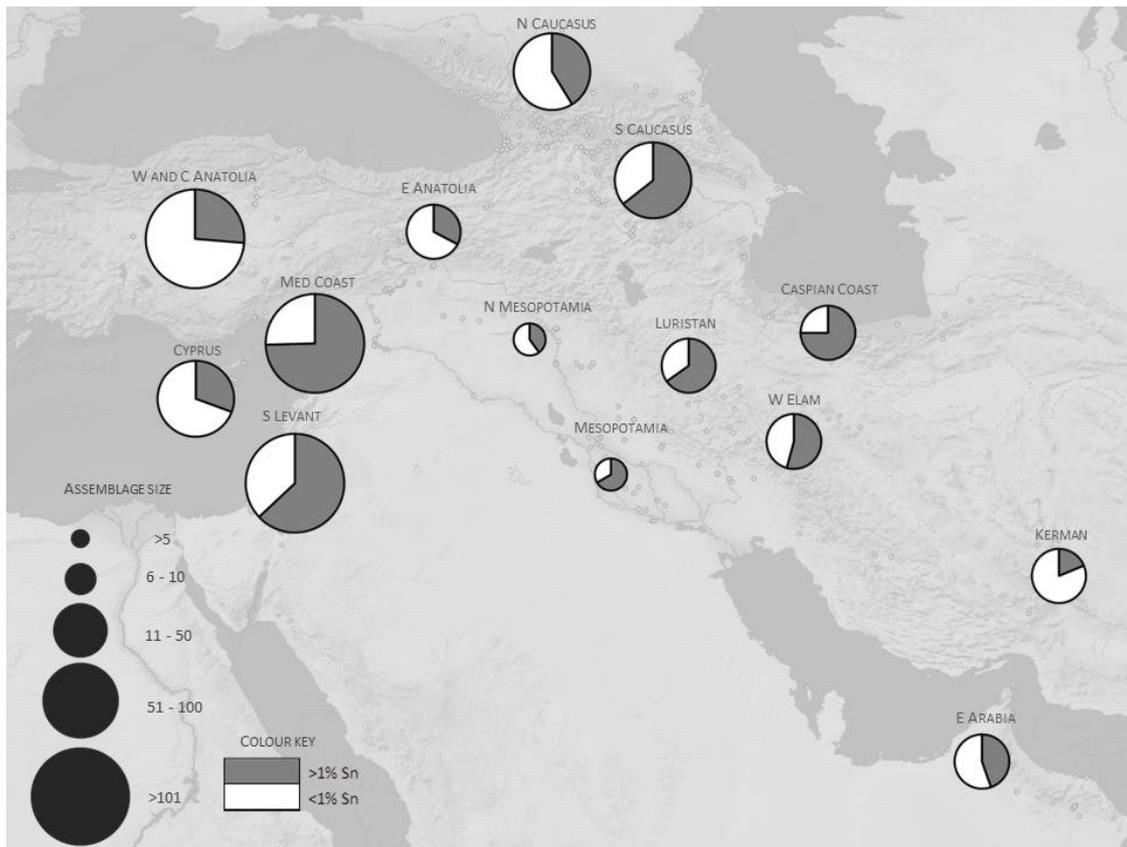


Figure 105: Mid-2nd millennium BCE percent of assemblage containing >1% Sn (grey) against objects containing <1% Sn (white)

Access to tin generally appears to have become more unequal across Southwest Asia during the mid-2nd millennium BCE if the sample sizes are considered reflective of regional copper use, and the tin-bronze to unalloyed-copper ratios are taken into account: the percentage of tin-bronze in copper assemblages larger than ten ranged from one third to three quarters of the assemblage. It is tempting to see this as a disruption of inter-regional trade, despite the widespread, impartial trading network of the International period. The assemblages from the mid-2nd millennium BCE reflect a system based on favours, diplomatic gifts, and shifting allegiances, as well as war and the collection of booty. The result of this system was unequal access to resources and acquisition based on good relations with neighbouring regions and the exclusion of enemies. Towards the end of this period

states also began to disregard the impartiality of trading ports: Egypt acquired a treaty of allegiance from Ugarit in the 14th c. BCE before the Hittites managed the same at a later date (Knapp 1986, p.43). By the terms of a treaty with the Hittites Amurru, in the Mediterranean Coast region, was forbidden to trade with Assyria or to let Assyrians access maritime trade across their land (Van de Mieroop 2016, p.178; Collins 2007, p.68). These changing allegiances would clearly have had a disruptive effect on trade between and across regions.

The coastal regions of Cyprus, the Southern Levant, and the Mediterranean Coast were flourishing economically, as demonstrated by the concentration of copper-base assemblages in this area. This possibly reflects the advantage of maritime trade over land-based routes, the latter of which are more easily frustrated. On the other hand, piracy and unfavourable conditions at sea could ruin any enterprise, for example the loss of the Ulu Burun cargo must have been economically devastating.

West and Central Anatolia had a surprisingly insignificant regional tin-bronze tradition, considering the importance of tin-bronze to the Hittite Empire (Chernykh 2017b; Yalçın 1999). In fact, during the mid-2nd millennium BCE the West and Central Anatolian copper-base assemblage has the largest number of non-tin copper objects in the whole of Southwest Asia. This therefore indicates that the region was lacking access to tin rather than a regional copper tradition, which would explain the frequent attempts of the Hittites to control the upper Euphrates valley and Northern Levantine Coast and thus control the trade network.

The tin content distributions of the Mediterranean and Cypriot tin-bronze assemblages from the mid-2nd millennium BCE (Figure 106) are once again very similar, suggesting cohesion through maritime trade. As Cyprus was very well connected with the rest of Southwest Asia at this time a stable source of tin is to be expected. Figure 107 shows the similarity in tin content distributions between the Southern Levant and West and Central Anatolian tin-bronze assemblages, with both regions having an emphasis on lower tin contents. The differing tin content distributions between the Mediterranean Region assemblage and the West and Central Anatolian assemblage is noticeable, and again may explain the repeated attempts of the Hittite Empire to control that region.

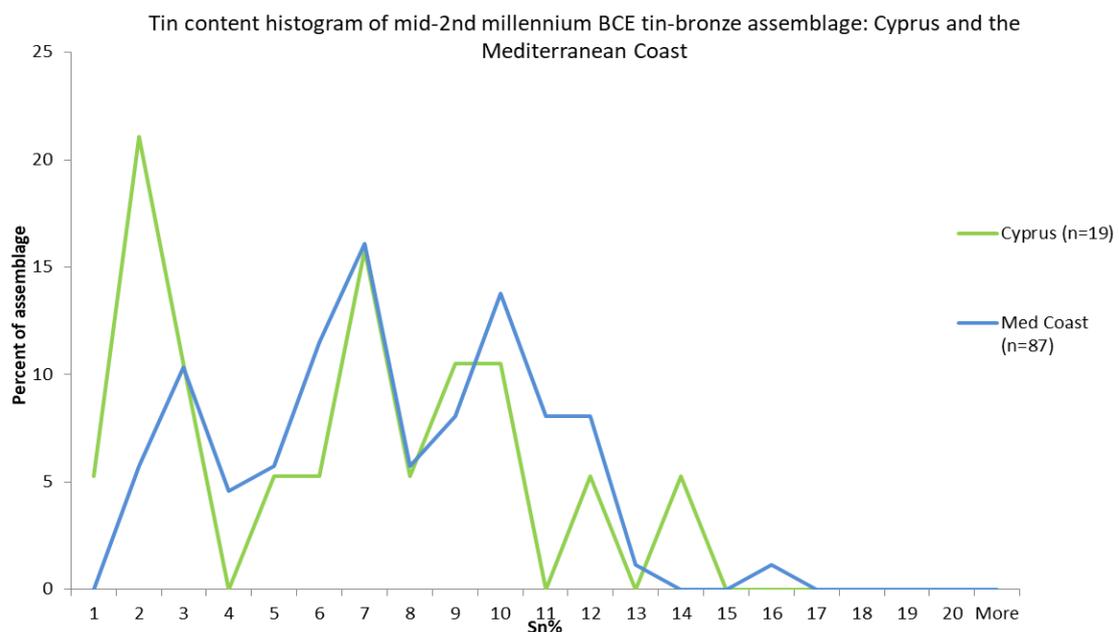


Figure 106: Histogram of tin content in the tin-bronze assemblages from mid-2nd millennium BCE Cyprus and Mediterranean Coast

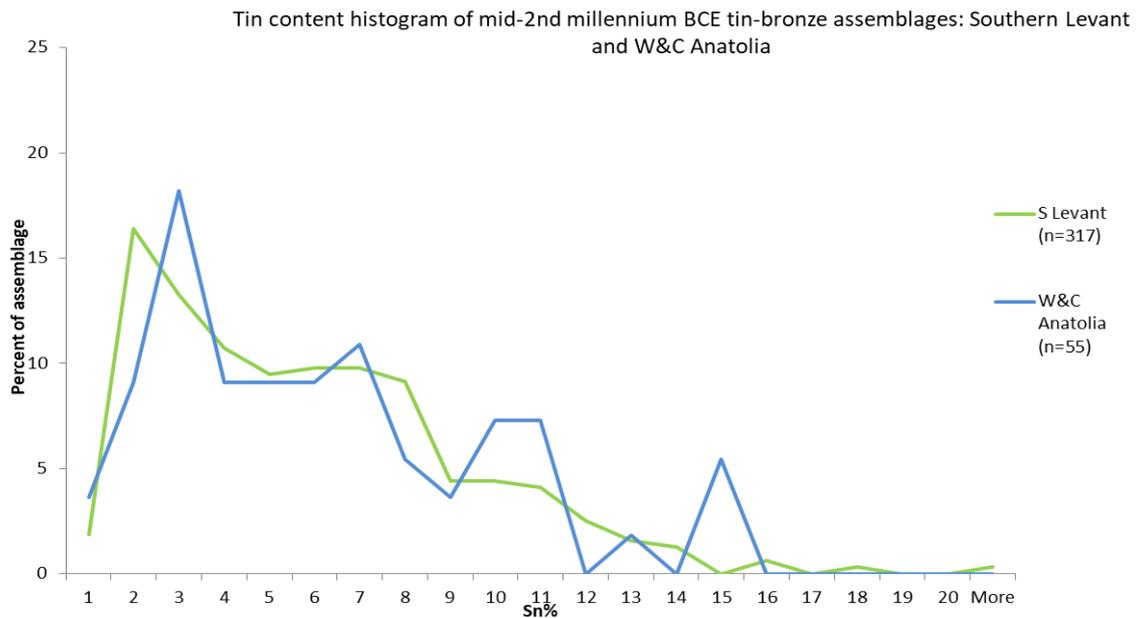


Figure 107: Histogram of tin content in the tin-bronze assemblages from mid-2nd millennium BCE Southern Levant and West and Central Anatolia

The change in alloying patterns which we began to see in the mid-2nd millennium BCE continued into the late 2nd millennium (Figure 108). Arsenical-bronze use decreased dramatically, making up a significant portion of the assemblage only on Cyprus. The lack of arsenical-bronze use elsewhere reflects the cessation of large-scale copper exports from Cyprus which collapsed with the Late Bronze Age c. 1200 BCE. The decrease in arsenic concentrations across Southwest Asia could also indicate general recycling of copper-objects in resource poor areas. Its continued use on Cyprus is to be expected owing the arsenic-rich resources of the island.

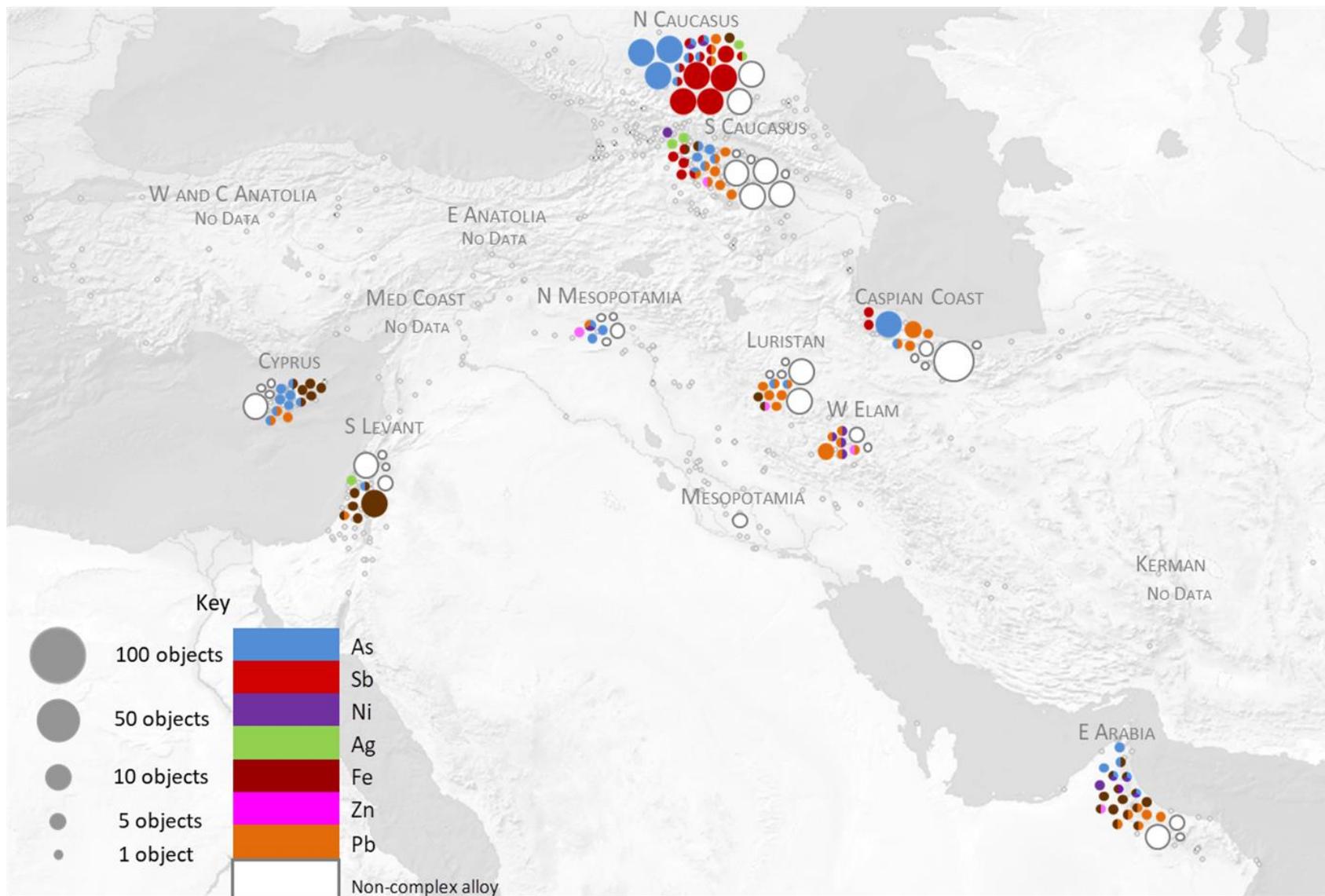


Figure 108: late 2nd millennium BCE regional copper-base assemblages indicating alloying elements in use (alloying elements considered as >1% As, Sb, Ni, Ag, Fe, Zn, Pb, and 'unalloyed copper')

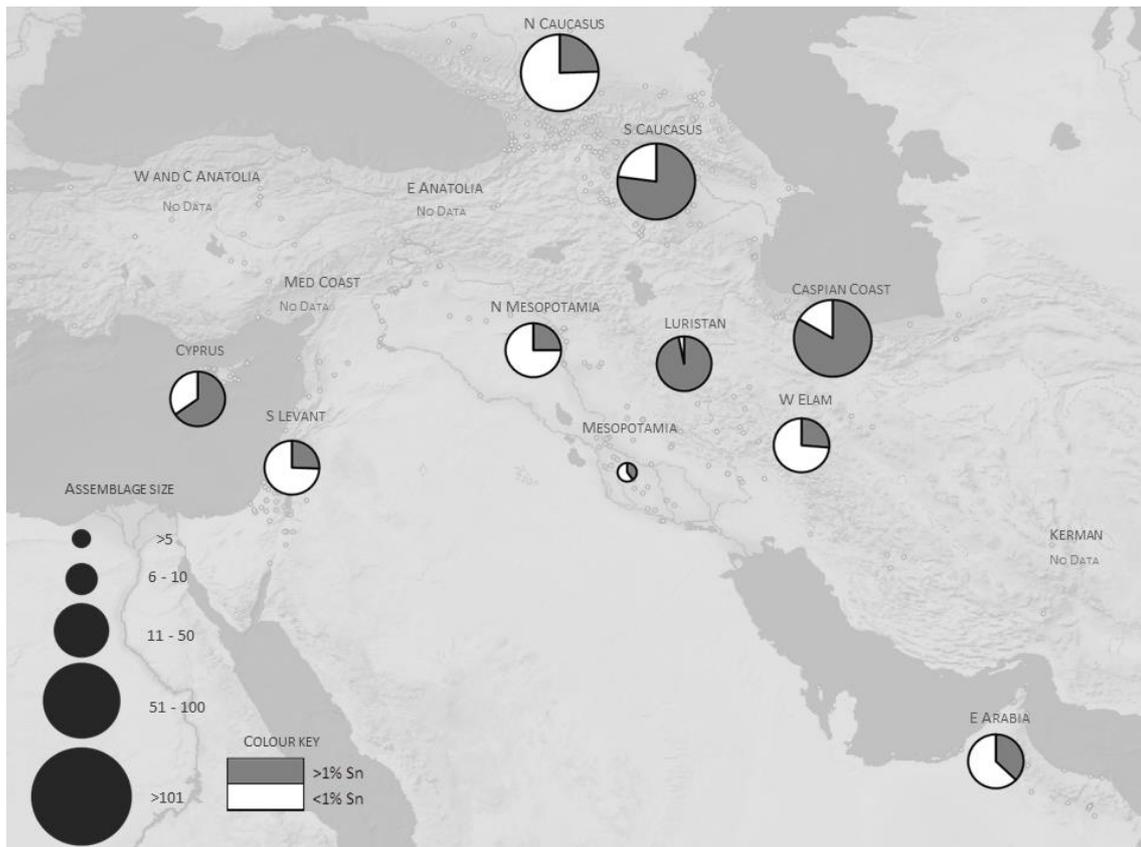


Figure 109: Late 2nd millennium BCE percent of assemblage containing >1% Sn (grey) against objects containing <1% Sn (white)

The collapse of the Bronze Age occurred at varying times in all regions; from c. 1300 BCE in Eastern Arabia and Iran; c. 1200 BCE in Mesopotamia, Northern Mesopotamia, the Caucasus and Anatolia; c. 1150 BCE in the Southern Levant, and 1050 BCE in Cyprus (Van de Mierop 2016; Knapp 2008). The Eastern Arabian tin-bronze tradition remained relatively unaffected by the collapse of the Bronze Age. As trade had ceased between Magan (Oman) and Southwest Asia in the middle of the 2nd millennium BCE, it was perhaps spared the shared disintegration of interdependent trading contacts, as presumably the region continued to trade with its supplier of tin. The region certainly moved almost immediately on to the Iron Age after the collapse of the Bronze Age, avoiding a long period of de-urbanisation (D T Potts 1993, p.200).

In a similar situation as Eastern Arabia, the transition into the Iron Age in the Caucasus was less abrupt than in the majority of Southwest Asia (Smith 2005, p.267) and tin-bronze use here consequently continued to be consistent, again possibly by virtue of its less intense contacts with the diplomatic kingdoms of Southwest Asia. The Caspian Sea Coast also had a continued emphasis on tin-bronze use. This may reflect a continued tin trade via northern Iran to the Southern Caucasus, however if the region had first access to tin we might expect to see a higher peak of tin content in the Caspian Coast tin-bronze assemblage, and a lower tin content in the Southern Caucasus. This is not the case (Figure 110): though the tin-bronze assemblage from the Southern Caucasus contains more objects with a lower tin content, there are also a greater number which also contain >15% Sn. The pattern of tin use in both regions is similar – suggestive of access to the same tin supply and reaching each region separately rather than sequentially.

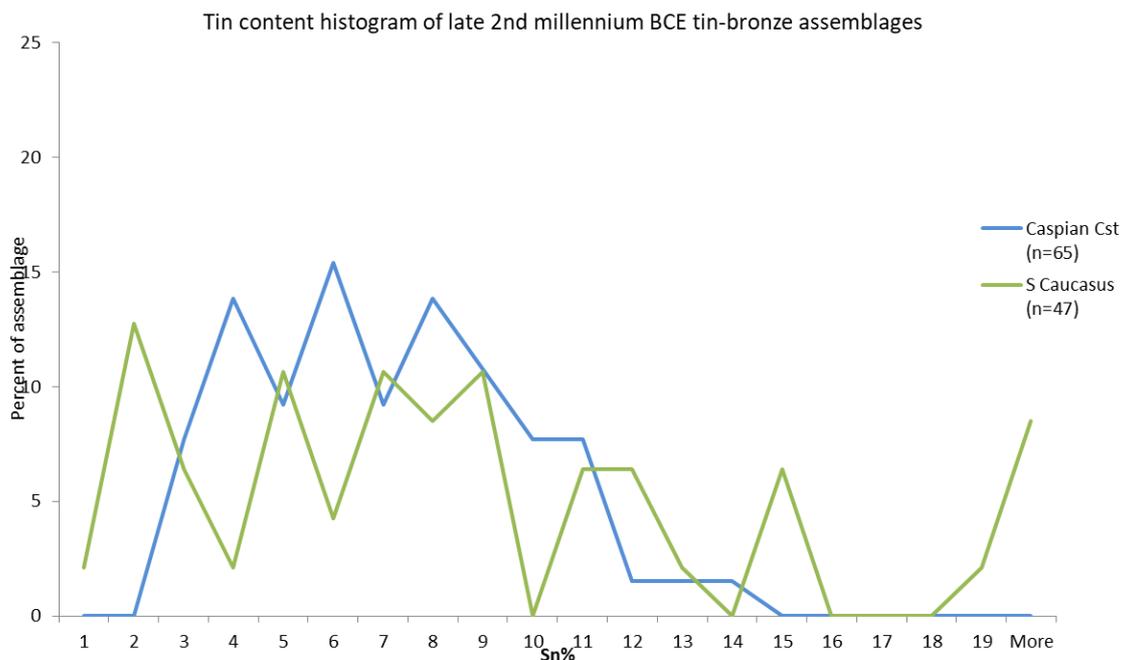


Figure 110: Histogram of tin content in the tin-bronze assemblages from late 2nd millennium BCE Caspian Sea Coast and Southern Caucasus

As mentioned earlier Cyprus did not see the end of the Bronze Age until the 11th c. BCE, and this is possibly owing to the advantages of geographic isolation (Steel 2013, p.10). The proportion of tin-bronze objects to copper objects increased from the mid-2nd millennium to the late 2nd millennium BCE assemblage but in terms of numbers had actually remained relatively consistent, decreasing from nineteen to seventeen. Despite presumed disruption of tin acquisition, the largest majority of tin-bronze objects contained ~8% Sn in the late 2nd millennium BCE, in comparison to a higher density of possibly diluted objects with ~2% Sn in the mid-2nd millennium BCE, when Cypriot trade was at its most extensive (Figure 111). Owing to continuation of maritime trade with the Levant and the Mediterranean, but also to the diminishing attempts of political interference from neighbouring regions, trade appears to have been more profitable for Cyprus at the time of the Bronze Age collapse than during the International period (Iacovou 2013; Knapp 2008).

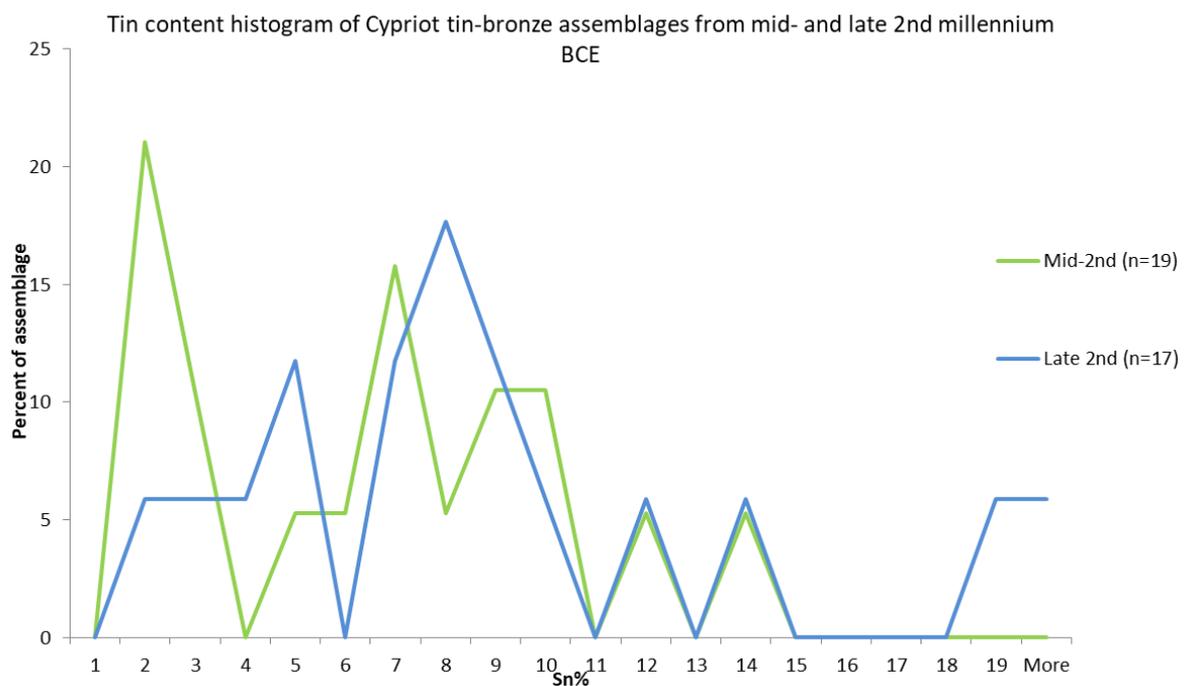


Figure 111: Histogram of tin content in the Cypriot tin-bronze assemblages from the mid-2nd millennium BCE and late-2nd millennium BCE

The copper-base assemblage in the Southern Levant also did not diminish at the same pace as in the rest of Southwest Asia, although there was a sharp decrease in the number of tin-bronze objects in use. The large discrepancy between sample sizes from the mid-2nd to late 2nd millennium BCE means the following observations must be treated cautiously: the percent of the tin-bronze assemblage made of lower tin content is higher in the late 2nd millennium BCE, however, in actual numbers there are far fewer objects containing lower tin than previously (Figure 112).

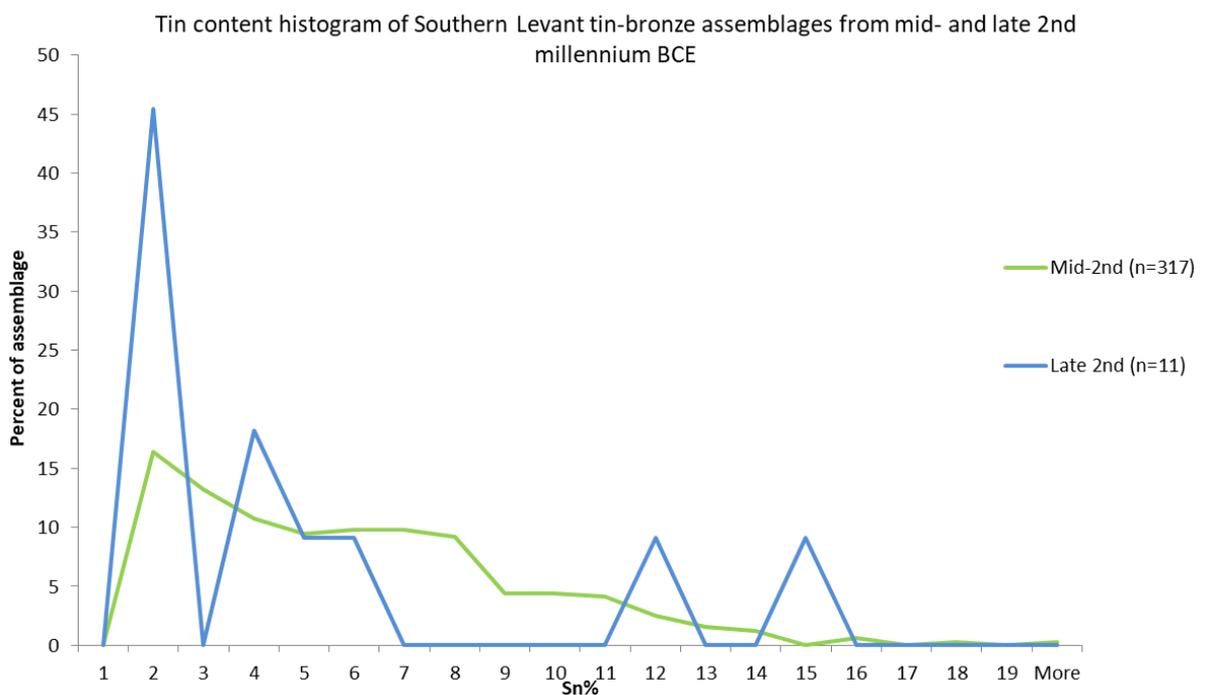


Figure 112: Histogram of tin content in the Southern Levantine tin-bronze assemblages from the mid-2nd millennium BCE and late-2nd millennium BCE

The asynchronous Southwest Asian Bronze Age collapse allowed some regions to continue their metallurgical traditions for varying amounts of time. The most significant effect of the lack of centralized trading networks was access to tin, but the geographically peripheral regions seem to have been the least affected by this –

possibly owing to access to other trading networks, or possibly due the exploitation of any available small local tin deposits.

7 Early 1st millennium BCE: a new tradition

The early 1st millennium BCE produces a completely altered pattern of copper-alloy use in Southwest Asia (Figure 113). Arsenical-bronze during this period makes up only around 10% of each assemblage, and also appears quite uniform between all regions. Leaded-copper use increased slightly from the previous time period, especially in the Southern Levant. The development of a lesser reliance on arsenical-bronze had been visible throughout the later part of the 2nd millennium BCE but appears to have stabilized in the early 1st millennium. The narrowing range of copper-alloys in use across Southwest Asia could indicate shared copper resources or perhaps the development of a shared metallurgical tradition.

The copper-base assemblage from Eastern Arabia is composed of different alloys from the other regions in Southwest Asia: it is the only region containing more than two objects with >1% Ni. As copper-nickel is characteristic of local copper ores, this indicates a lack of copper exports to Southwest Asia. The difference in alloying patterns supports the picture of a region somewhat isolated from the rest of Southwest Asia (Magee 2004). Though there are a significant number of leaded-copper objects which could indicate some connection to the rest of Southwest Asia, such trade is not documented. It is unfortunate that there is so little data from the neighbouring regions of Iran with which to compare the Eastern Arabian assemblage, owing to the trade in ceramics across the Gulf.

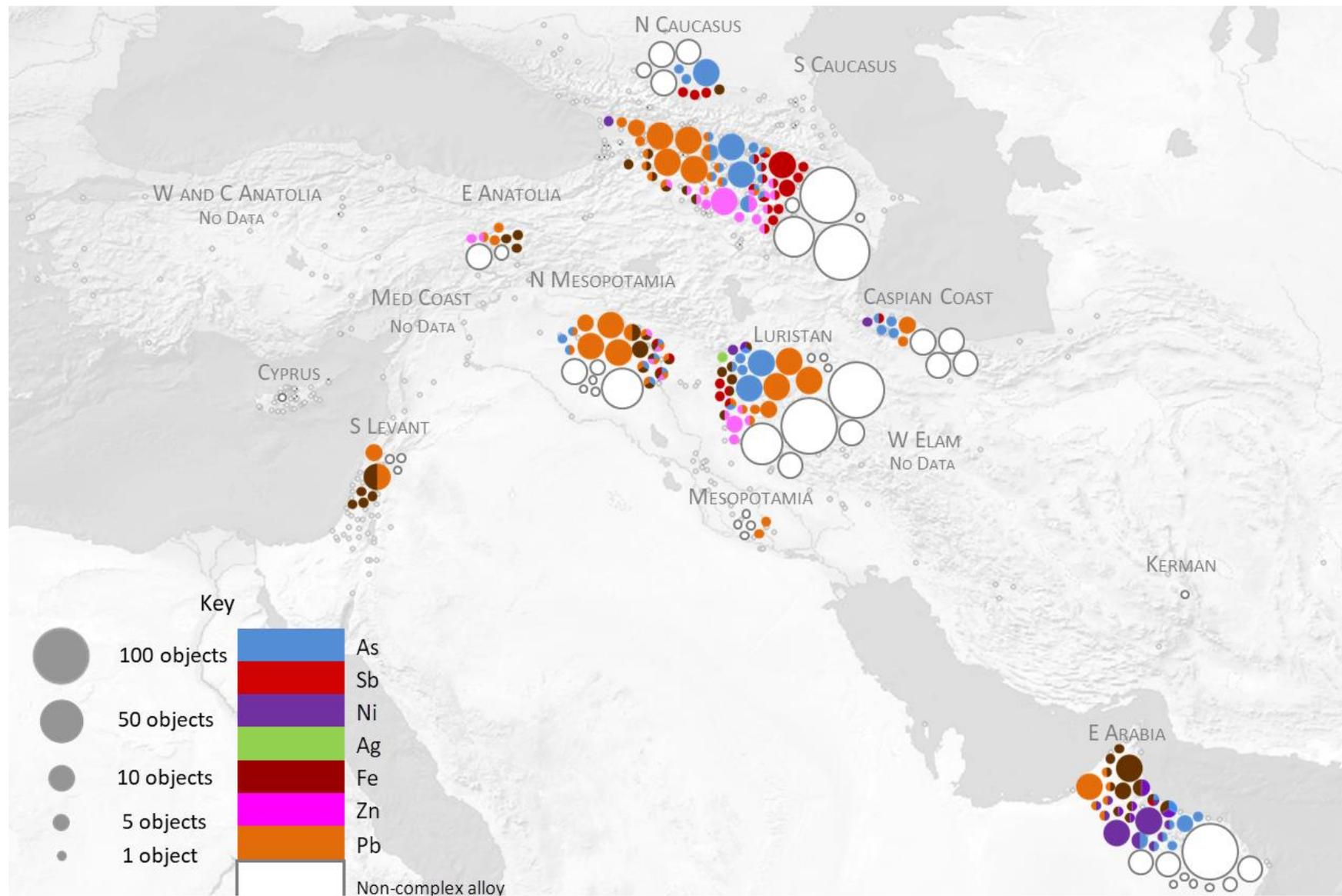


Figure 113: early 1st millennium BCE regional copper-base assemblages indicating alloying elements in use (alloying elements considered as >1% As, Sb, Ni, Ag, Fe, Zn, Pb, and 'unalloyed copper')

Zinc-rich copper (>1% Zn) is present in significant quantities in the Southern Caucasus and Luristan in comparison to previous periods and is also present in Eastern Anatolia and Northern Mesopotamia. These regions were interconnected during the early 1st millennium BCE, whether by land dispute or trade, and this may account for the spread of such an unusual alloy. The zinc-rich copper objects from Northern Mesopotamia are different to the other zinc-rich assemblages. Firstly, the objects are zinc-rich copper alloyed with at least two other alloying elements at >1% (e.g. a copper-zinc-lead-iron-arsenic alloy), suggestive of mixed metal, and secondly, they are all small tools. In Luristan, Eastern Anatolia and the Southern Caucasus zinc-rich alloys are generally copper alloyed with zinc only, and have been used to produce vessels, jewellery, or horse equipment, which are all rather more high-status object types. Possibly the heavily mixed small objects represent recycled scrap sent as tribute to Assyria, or copper mixed once it had arrived.

Patterns of tin-bronze use changed significantly from the 2nd to the 1st millennium BCE. The most obvious change possibly only reflects regions of past archaeometallurgical interest and an uneven regional approach to analytical data collection. However regions with very little analytical data are also regions which took longer to recover from the collapse of the Bronze Age. The most interesting development is that most regions with tin-bronze present are dominated by the alloy (Figure 114). This apparent concentration of the tin trade in the northern and eastern regions of Southwest Asia is consistent with the possibility of tin travelling via the Caspian Coast or through the Caucasus.

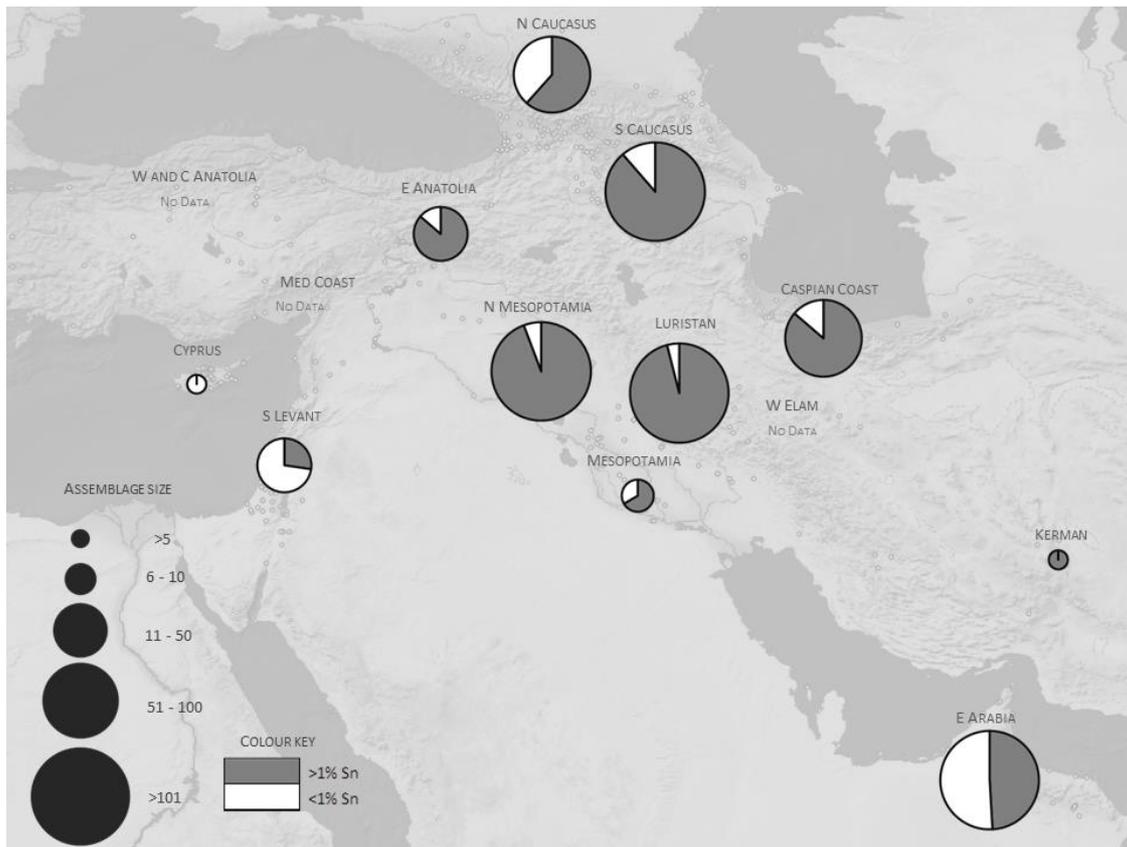


Figure 114: Early 1st millennium BCE percent of assemblage containing >1% Sn (grey) against objects containing <1% Sn (white)

Figure 115 depicts the distribution of tin content in the tin-bronze assemblages from the Caspian Coast and the Southern Caucasus in the early 1st millennium BCE. The peak of tin content in the objects from the Caspian Coast centres around 8 – 10% Sn, and indicates an industry lacking in large-scale re-use of metal. The tin content from the objects in the Southern Caucasus indicate that the peak tin content is around 7% Sn, and a larger percent of objects contain between 2 and 6% Sn. This could indicate a movement of tin via the Caspian Sea Coast. Stöllner *et al.* (2011, p.247) state that tin was not transported west from Eastern Kazakhstan via Northern Iran as the regional metallurgy does not support it, however the tin content of available tin-bronzes would be in keeping with a western direction of tin travel. This was not the case pre-2500 BCE.

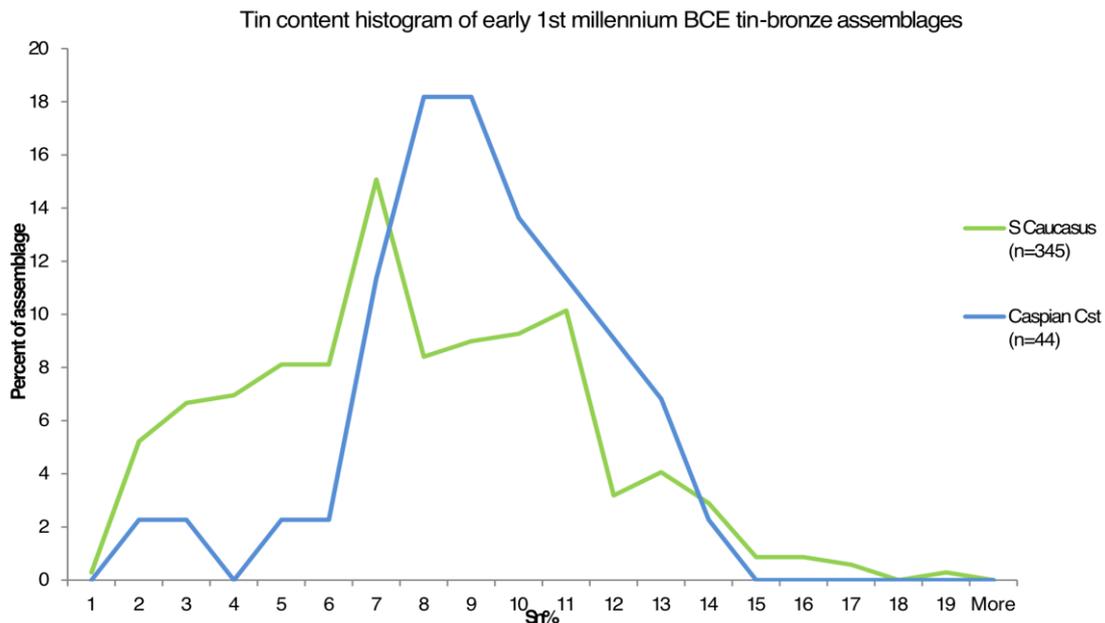


Figure 115: Histogram of tin content in the early 1st millennium BCE tin-bronze assemblages from the Southern Caucasus and the Caspian Sea Coast

It is always possible that tin could have travelled along a northern route: from Kazakhstan via the Steppe and through the Northern Caucasus (Stöllner *et al.* 2011). Figure 116 shows the same tin content distributions as above with the tin content distribution of the Northern Caucasus tin-bronze assemblage added. This distribution differs in that there are two main peaks in tin content from the Northern Caucasus tin-bronze assemblage: the first lies at 2% Sn, and the second is the same as the tin peak of the Southern Caucasian assemblage. This does not indicate an industry with more availability of tin than that of the Caspian Sea Coast and could in fact indicate a tin-bronze industry that relies more on the re-use of tin-bronzes. Unfortunately both the assemblages from the Caspian Coast and Northern Caucasus lack the numbers to provide anything more than speculation at this point.

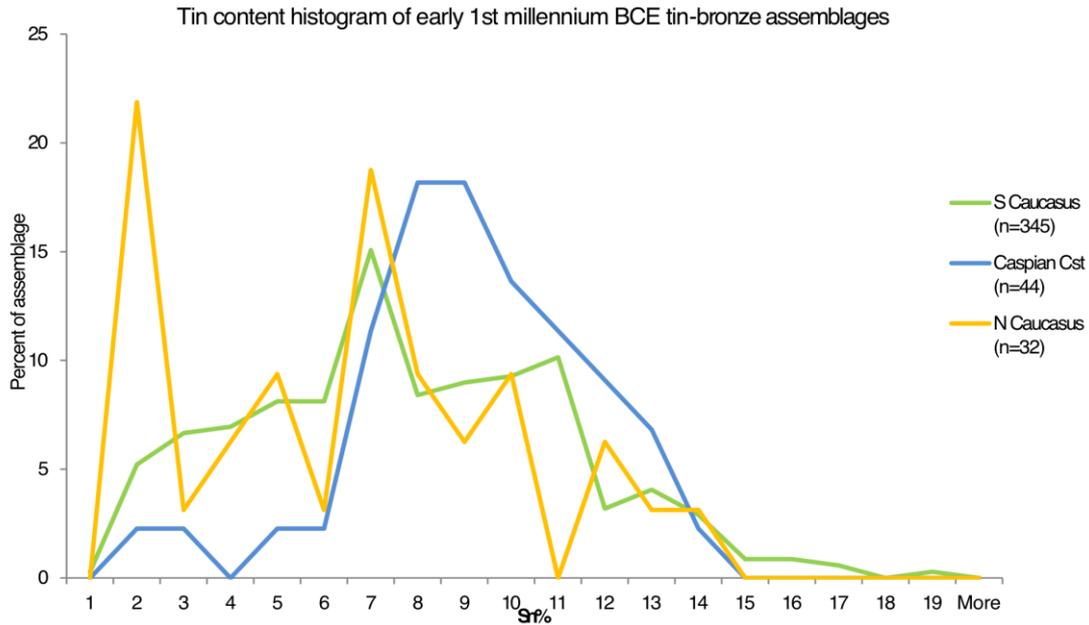


Figure 116: Histogram of tin content in the early 1st millennium BCE tin-bronze assemblages from the Southern Caucasus, Caspian Sea Coast, and the Northern Caucasus

The heavy tin-bronze use in the northeast corner of Southwest Asia is also in keeping with the level of communication and interaction which is known to have been taking place between the Southern Caucasus, Eastern Anatolia, Northern Mesopotamia and Northwest Iran, whether due to clashes over territory, payment of tribute, or simple trade (Barnett 1982; Dan 2010; Castelluccia 2017a; Van de Mieroop 2016).

It is also possible that at this time tin is sourced from the Deh Hosein mine, or other undiscovered sources located in the Iranian highlands (Cuénod 2013, p.187). The high ratio of tin-bronze use in Luristan certainly supports this theory, as does the tin content distribution in Figure 117. This diagram also shows an astounding similarity between the tin content of Luristan tin-bronzes and Assyrian tin-bronzes. This could indicate a shared metallurgical tradition, or access to the same nearby sources.

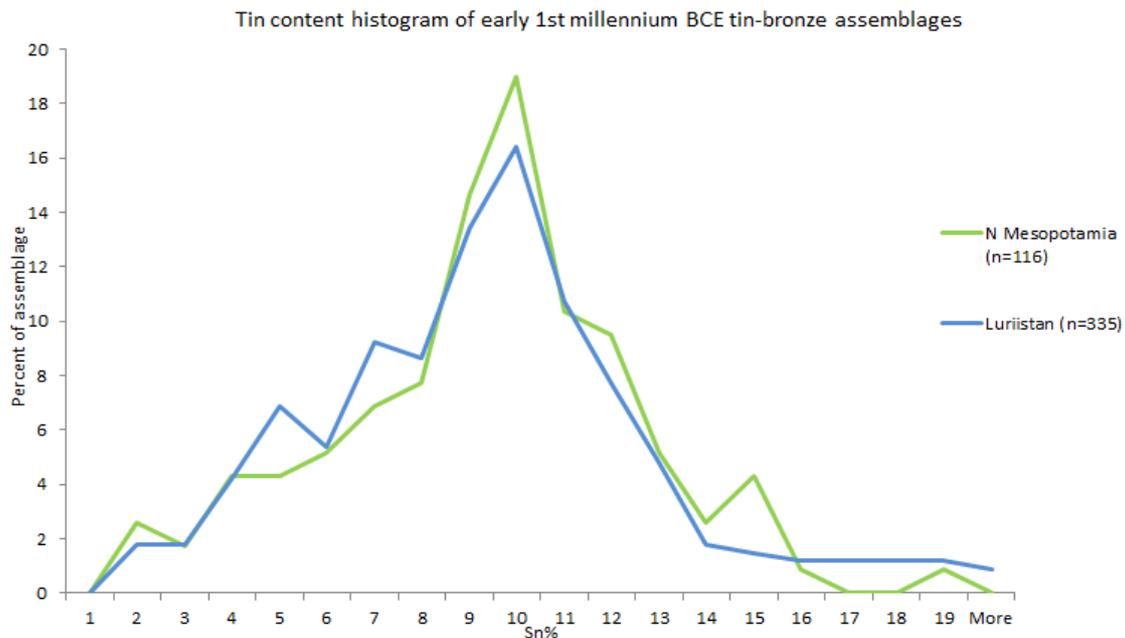


Figure 117: Histogram of tin content in the early 1st millennium BCE tin-bronze assemblages from Northern Mesopotamia and Luristan

The early 1st millennium BCE witnessed a great change in approach to copper metallurgy and represents a possible shift in metallurgical organisation and tradition. The range of alloys decreased across Southwest Asia resulting in a more homogenous archaeometallurgical record, and tin-bronze finally became the dominant alloy at the beginning of the Iron Age. These changes in alloying patterns could indicate that metalsmiths had both settled on and acquired consistent access to the alloying element of choice. However it remains to be seen how different the eastern Mediterranean tin-bronze tradition would have been, and whether this cohesion of northeastern regions relies on a dearth of evidence from the southwest.

8 Additional alloying elements throughout time

8.1 Iron-rich copper

Iron-rich copper also occurs regularly within the database but cannot be considered as an alloy in the traditional sense and has mainly been left out of the preceding discussion. The presence of >1% iron has a detrimental effect on the physical properties of copper which render it virtually unworkable. Generally speaking, it needs to be processed before it can be successfully manufactured into usable artefacts. As iron is relatively prone to oxidation, its presence between 1 – 10% in copper is considered typical for unrefined material (see below) (Craddock and Meeks 1987). However, the relatively ubiquitous distribution of objects containing >1% iron across Southwest Asia from the mid-3rd millennium BCE onwards, and their more restricted presence in Eastern Anatolia, Mesopotamia, the Southern Caucasus, Southern Levant, and Western Elam in earlier periods is worthy of further consideration.

This section will explore possible explanations for the low-frequency, but widespread presence of significant quantities of iron in the copper of southwestern Asia. And some specific discussion of these iron-rich copper objects, in order to understand why such an apparently undesirable mixture has been so often found in Bronze Age contexts. It is necessary to allow for the possibility of other post-depositional and analytical factors influencing the presence and identification of iron in copper (e.g. Shalev and Northover 1993).

Iron becomes soluble in molten copper only at high temperatures and in reducing atmospheres, and as such its presence in copper has often been seen as indicative of increased sophistication of pyrometallurgical techniques, e.g. better furnaces

and the development of slagging processes (Cooke and Aschenbrenner 1975; Craddock and Meeks 1987). It has also been seen as use of copper oxide ores rather than copper sulphides (Tylecote 1980). If iron oxide was added as a flux, copper could have absorbed iron as it drained through the layer of slag to the bottom of the furnace (Craddock and Meeks 1987; Tylecote 1980). There is a rough (though complex) relationship between the temperature of the smelt and the amount of iron absorbed into the molten copper (Cooke and Aschenbrenner 1975).

Iron may also be introduced into the copper by the addition of speiss. As mentioned in section 2.3 of this chapter, there are two types of speiss, ferrous and base-metal, the former of which concerns us here. The most common type of ferrous speiss discussed in the literature regarding ancient metallurgy is iron-arsenide, which has been debated as a method of purposefully increasing the arsenic concentration in copper for the production of arsenical-bronze (Thornton *et al.* 2009; Rehren *et al.* 2012). Significant evidence for the use of ferrous speiss is mainly located in regions of modern Iran, though a few examples (indirect and direct evidence) have been found elsewhere: a lump of heat-treated iron-arsenic material from EB/MB Jericho; iron-arsenic ingots from mid-2nd millennium BCE Boğazköy in Anatolia; and a fragment of ferrous-speiss from Kamid-el-Loz in modern Lebanon, to name those found within this research area (Thornton *et al.* 2009, p.309). By far the most significant finds relating to ferrous speiss were found at Arisman, Western Iran: twenty tonnes of slag were reported, which contained a mixture of slag from smelting copper and slag from producing iron-arsenide (Rehren *et al.* 2012, p.1722). The conclusion was that not only does this provide

evidence for the intentional production of speiss, but that it was a routine operation, which consequently led to the mixing of iron-arsenide with copper ore or to metallic copper in order to boost the arsenic content and create arsenical-bronze (*ibid.* p.1726). It was also questioned whether the speiss produced here was also intended as a trading commodity, thus allowing regions lacking in arsenic-rich copper ores to produce arsenical-bronze. The addition of speiss is an intriguing theory: from the 3rd millennium BCE onwards the addition of tin to a copper smelt or molten copper was presumably a well-known technique, and it is possible that this could be mirrored in the production of arsenical-bronze. The addition of extra material to improve or change the existing metal in some way may have been a tradition that existed beyond tin-bronze production.

Refining of the resultant copper is mentioned in both contexts. Craddock and Meeks (1987) state that copper containing 1 – 10% iron would have been easily refined to improve the behavioural qualities. Rehren *et al.* (2012) mention the refining of iron-arsenic-copper to explain how low-iron arsenical-bronze would be the resulting material, as analyses of metal prills on site suggest equal quantities of iron and arsenic in the initial product. Refining iron out of copper is simple: “it was melted in an open crucible and the iron allowed to oxidise and then form a slag by sprinkling clean sand/crushed quartz onto the surface” (Craddock and Meeks 1987, p.192). In the case of objects smelted with speiss this process would oxidise the iron but not the arsenic, resulting in an arsenic-rich, iron-low copper (Rehren *et al.* 2012, p.1726). In a series of experiments Tylecote found that the iron content could be reduced to ~0.5% but that refinement further than this was increasingly difficult (Craddock and Meeks 1987, p.192). If speiss was used, we might therefore

expect >0.5% iron and several percent of arsenic, and if copper was formed through the use of iron as a flux, iron should also be present at ~0.5% but the remaining arsenic composition would be dependent on the choice of ore.

In the interest of understanding the iron-rich copper objects in the database further, the assemblages will be looked at in keeping with both theories. The first question is that if copper was considered unrefined and substandard when it contained >1% iron, why are there so many objects made of copper that has not had the iron removed? Especially given the ease by which iron can be reduced to <1%. This will be studied by looking at the typology of objects and the provenance of iron-rich copper objects from late 3rd millennium Mesopotamia and Eastern Arabia, and from across Southwest Asia in the late 2nd millennium BCE. The second question asks if there is a correlation between arsenic and iron, and though there is no substantial evidence for it outside Iran, is it possible that arsenic-speiss was used in the production of Southwest Asian arsenical-bronze?

i. Copper containing >1% iron

In the late 3rd millennium BCE, 16% of the Mesopotamian copper-base assemblage and 19% of the Eastern Arabian copper-base assemblage contained >1% iron. Figure 118 shows the Eastern Arabian copper-rich assemblage split by object type and the ubiquity of that object type within the assemblage. The most common object category made of copper containing >1% iron is 'produced material' from metallurgical activity – all of these are ingots containing between 1 and 6% iron. If Craddock and Meeks' (1987) definition of 'unrefined' copper is followed, then these ingots could represent that trade in raw material occurred, to be refined at

its destination. It is also interesting that 35% of all ingots from late 3rd millennium BCE Eastern Arabia contained 1-6% iron, and these iron-rich ingots are found at all sites at which <1% iron copper ingots were also located. This suggests two things: trade in copper containing 1 – 6% iron was relatively common (either within Eastern Arabia or perhaps along the Gulf), and that this was a regional tradition, rather than representative of copper made at one site.

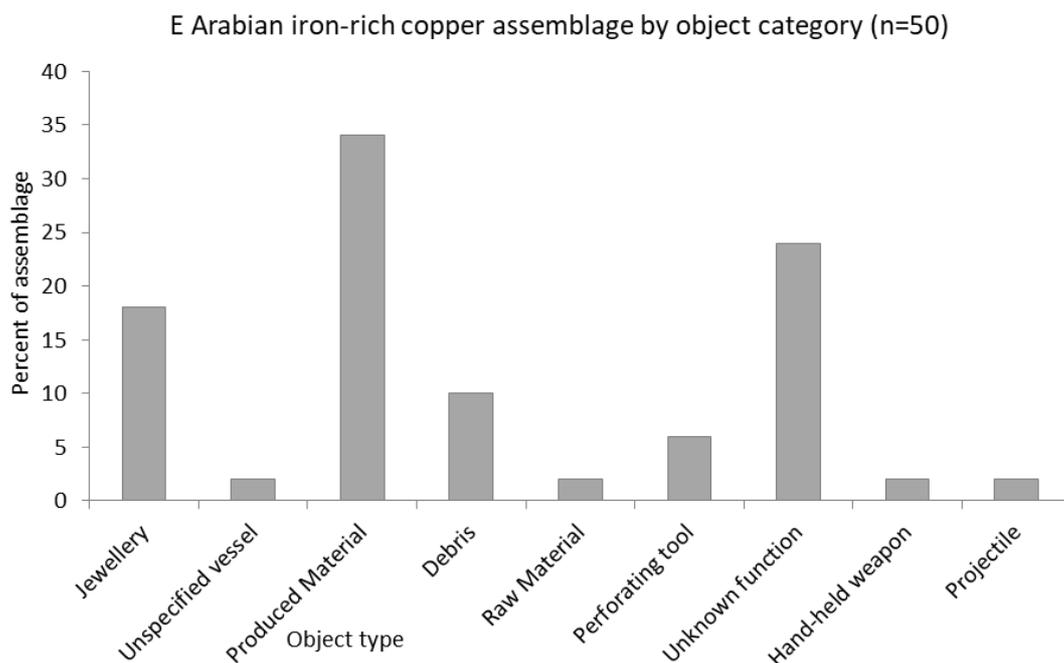


Figure 118: ubiquity of object type across iron-rich copper assemblage from late 3rd millennium BCE Eastern Arabia

In Mesopotamia on the other hand (Figure 119), the object categories most represented by copper iron are dress items (mostly pins), unspecified vessels, and hand-held weapons (daggers and axes). In total there are two hundred and thirteen iron-rich copper objects: this implies that copper containing >1% iron was either imported to Mesopotamia fairly regularly, or iron was regularly added to Mesopotamian copper. As iron in copper is considered to have a detrimental effect on copper it seems unlikely that the combination of copper and iron would have

been intentionally fabricated in the workshop, it therefore appears that iron-rich copper was used to produce finished objects without removal of the iron content beforehand.

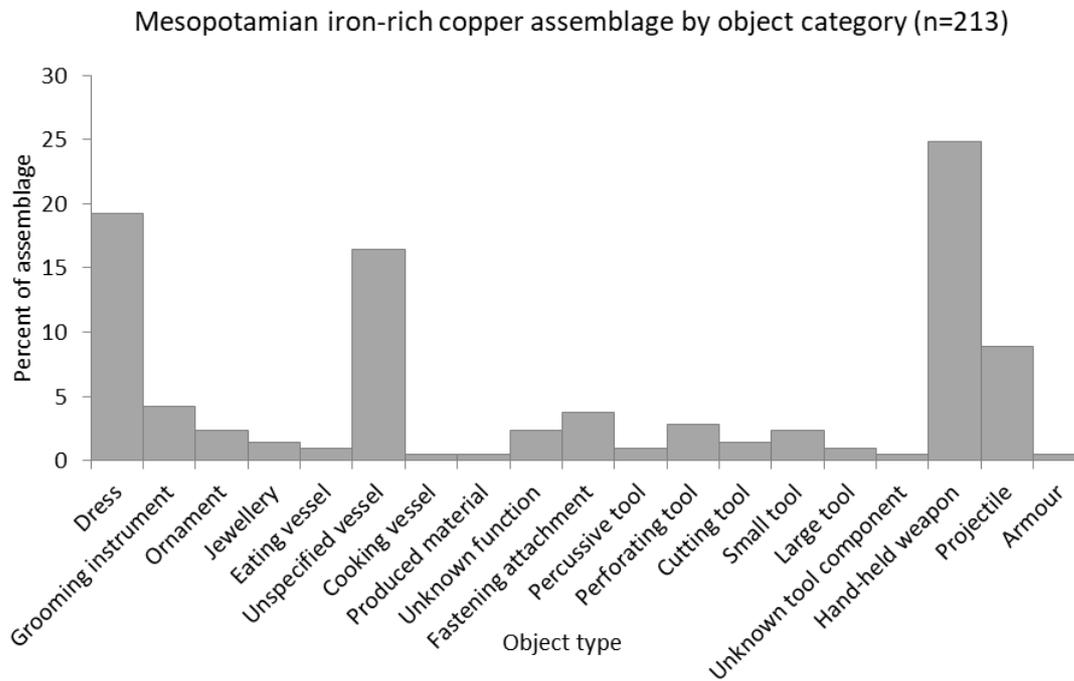


Figure 119: ubiquity of object type across iron-rich copper assemblage from late 3rd millennium BCE Mesopotamia

If copper containing >1% iron does represent unrefined material, possibly from Eastern Arabia owing to the presence of ingots there, it could be that this represents purposeful trade in substandard copper and recalls the complaint of a Mesopotamian to Ea-Nasir about the quality of ingots sent from Dilmin (Telmun) c. 1750 BCE, and the promise to inspect the ingots personally in the future (Oppenheim 1967, pp.82–3). It is possible high quantities of iron in the copper ingots were what rendered them poor quality.

The complaint to Ea-Nasir also potentially highlights the organisational structure of the Mesopotamian copper industry. It is mentioned in the text that Nanni (the writer of the complaint) has provided the palace with 1080 pounds of copper on

the behalf of Ea-Nasir, and that somebody named Umiabum has also gifted the palace with the same quantity of copper (Oppenheim 1967, p.83). This could indicate a system based around *redistribution*, where goods are centrally collected and then divided amongst people and workshops. If this was the case then we might expect to see an even distribution of copper compositions across all object types, especially if all ingots or raw material were treated in the same way. Comparison of Figure 119 and Figure 120 indicates that in fact the distribution of iron-rich copper across the typological range almost exactly matches that of the distribution of all copper across the typological range of copper objects in the late 3rd millennium BCE Mesopotamia. It therefore is unlikely to have been that only one workshop, or a handful of metalsmiths used iron-rich copper, but that its fabrication into finished objects was a regional tradition.

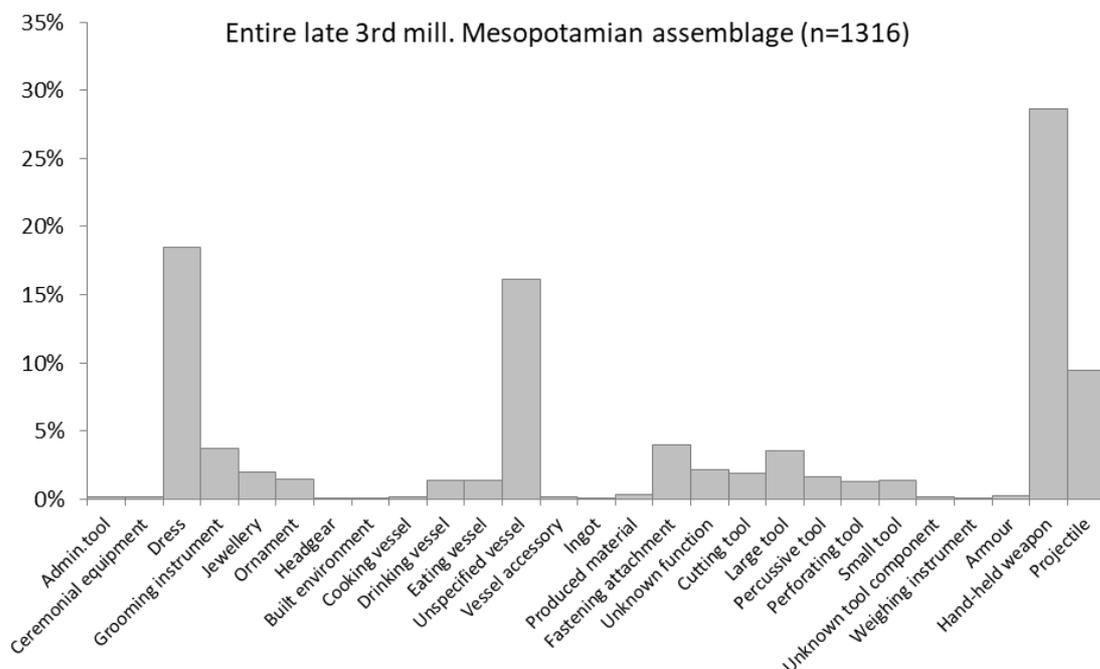


Figure 120: typological distribution of entire late 3rd millennium BCE Mesopotamian copper assemblage

The distribution of iron content in all iron-rich copper objects is quite similar in both Mesopotamia and Eastern Arabia, despite the fact that the majority of Eastern Arabian copper-rich objects are ingots, raw material, and metallurgical debris and the objects in Mesopotamia are finished objects (Figure 121). Most iron contents also peak at 2 – 3%. This use of iron-rich copper for finished objects could be the consequence of several possibilities: first, that all copper provided to the workshop was used, regardless of its quality; second, that the addition of other elements such as tin, arsenic, or lead offset the detrimental effect of iron; third, the detrimental effect of iron in copper is not as severe as previously assumed. Modern metallurgy uses a ‘master alloy’ of copper-iron (10% to 50% iron) as a grain refiner for brass or aluminium bronze, or for improving the mechanical qualities of low alloyed coppers (AZoM.com 2012). This modern use of copper-iron could indicate that iron-rich copper was not an undesirable mixture for ancient craftspeople, though more research is necessary.

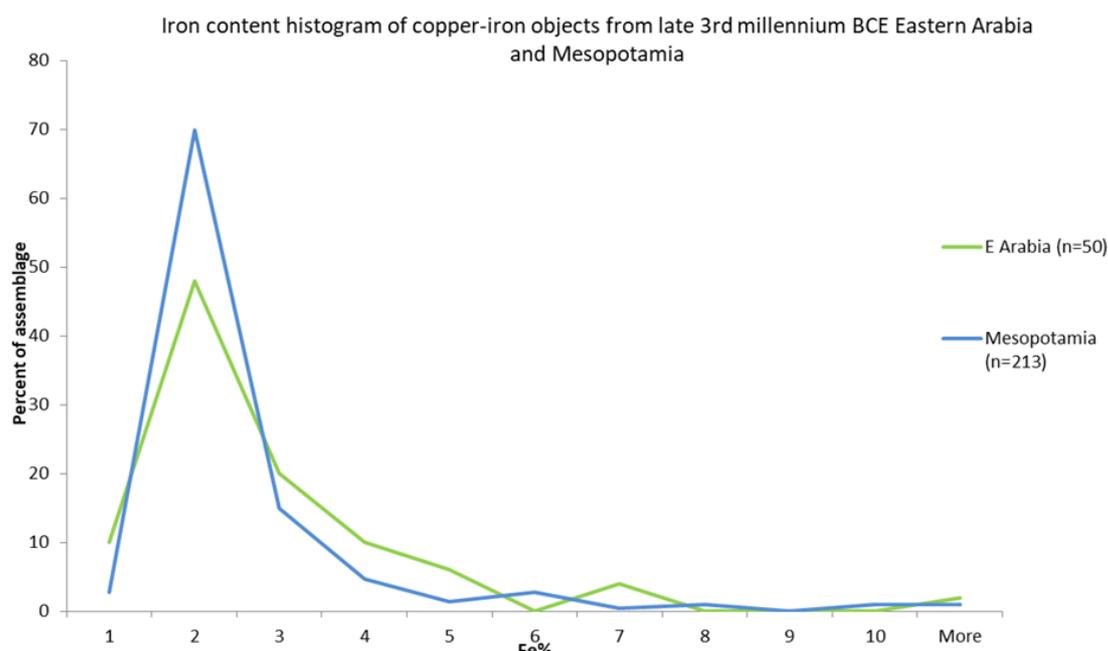


Figure 121: iron content distribution of iron-rich copper (>1% Fe) assemblages from late 3rd millennium BCE Eastern Arabia and Mesopotamia

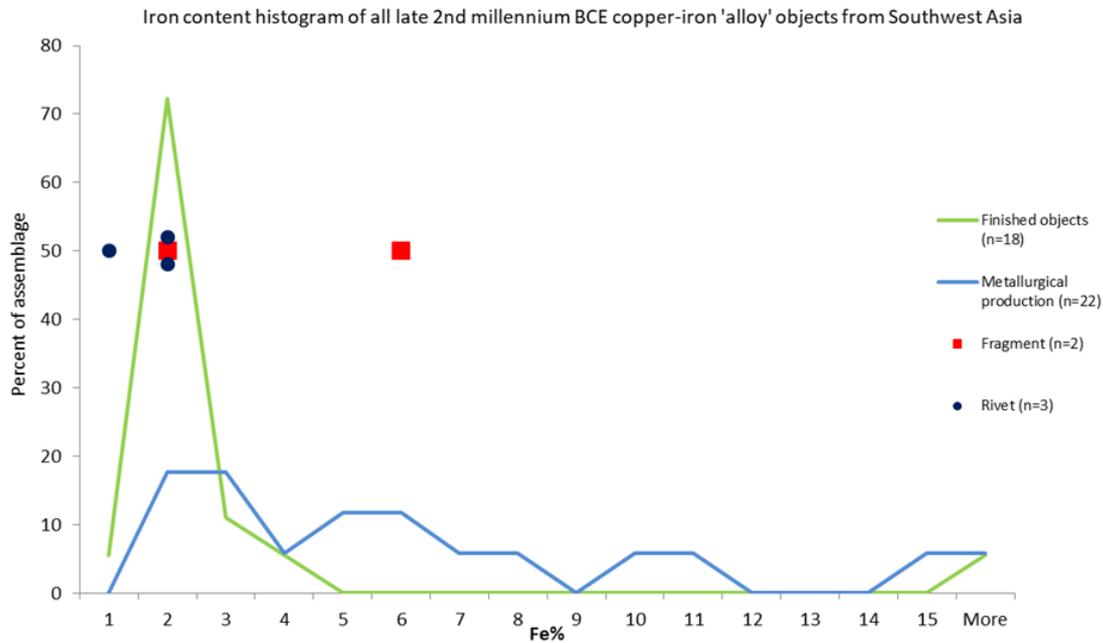


Figure 122: histogram of iron content distributions of all Southwest Asian late 2nd millennium BCE iron-rich copper objects, which have been divided into two categories: 'finished objects' and 'metallurgical production', plus the iron contents of 5 other objects which fit in neither category (Tylecote 1982; Knapp and Cherry 1994; Weeks 1999; Mahboubian 1997; Oudbashi and Hasanpour 2016; Kashkay and Selimkhanov 1973; Yahalom-Mack *et al.* 2014; Yagel *et al.* 2016; Philip *et al.* 2003)

If we compare the iron content distributions of the late 3rd millennium Eastern Arabian and Mesopotamian assemblages with the entire Southwest Asian iron-rich copper assemblage from the late 2nd millennium BCE we can see that there was a difference in approach towards the material in the later period. Unfortunately they cannot be directly compared regionally owing to the lack of data from late 2nd millennium BCE Mesopotamia, and the following discussion includes data from Cyprus, the Levant and Eastern Arabia. Figure 122 represents all objects from Southwest Asia made of iron-rich copper, which have been split into two categories: metallurgical production (waste copper, ingots, and 'raw copper'), and finished objects (mainly weapons and jewellery). The finished objects predominantly have an iron composition ~2%, whereas the objects relating to metallurgical production contain higher quantities. This is suggestive of copper that was refined to lose iron before being fashioned into objects as there is a

typological difference. The presence of finished objects with an iron composition ~2% could again indicate that iron was not necessarily detrimental to its behavioural qualities.

ii. Addition of speiss

To study the potential addition of speiss in the production of copper, certain aspects of the material have been taken into consideration. Firstly, the addition of iron-arsenide speiss has been hypothesised as a method of introducing significant levels of arsenic into the copper, resulting in an arsenic-rich copper (Rehren *et al.* 2012, p.1726). As arsenic-bearing minerals can easily be smelted into arsenical-bronze, the benefit of adding speiss was presumably the ability to control the final composition, so we must therefore expect to find perceptible levels of arsenic in the final material. 3% arsenic as outlined by Lechtman (1996), Killick (2014), Mödlinger *et al.* (2017), and Kuijpers (2017) has been taken in the following examples as this lower boundary. Secondly, the iron content need not be high as it can be easily refined out without an effect on arsenic levels (Rehren *et al.* 2012, p.1726). However it should be above >0.5% iron since removal of iron further than this was shown by Tylecote to have been very difficult (Craddock and Meeks 1987, p.192). To represent these behavioural and production limitations, the chemical data has been divided into blocks of <0.5%, 0.5 – 3%, and >3% for both iron and arsenic. The percentage of the regional assemblages that fall into each of these categories has then been calculated. The early 3rd millennium BCE was chosen owing to its chronological proximity to the Arisman large-scale production of speiss, to ascertain whether it could have been exported. This is then compared

with the early 1st millennium BCE, as arsenical-bronze traditions were quite depleted at this time, but iron contaminants are thought to have been brought about by the smelting of copper in iron bloomery furnace (Cooke and Aschenbrenner 1975, p.264).

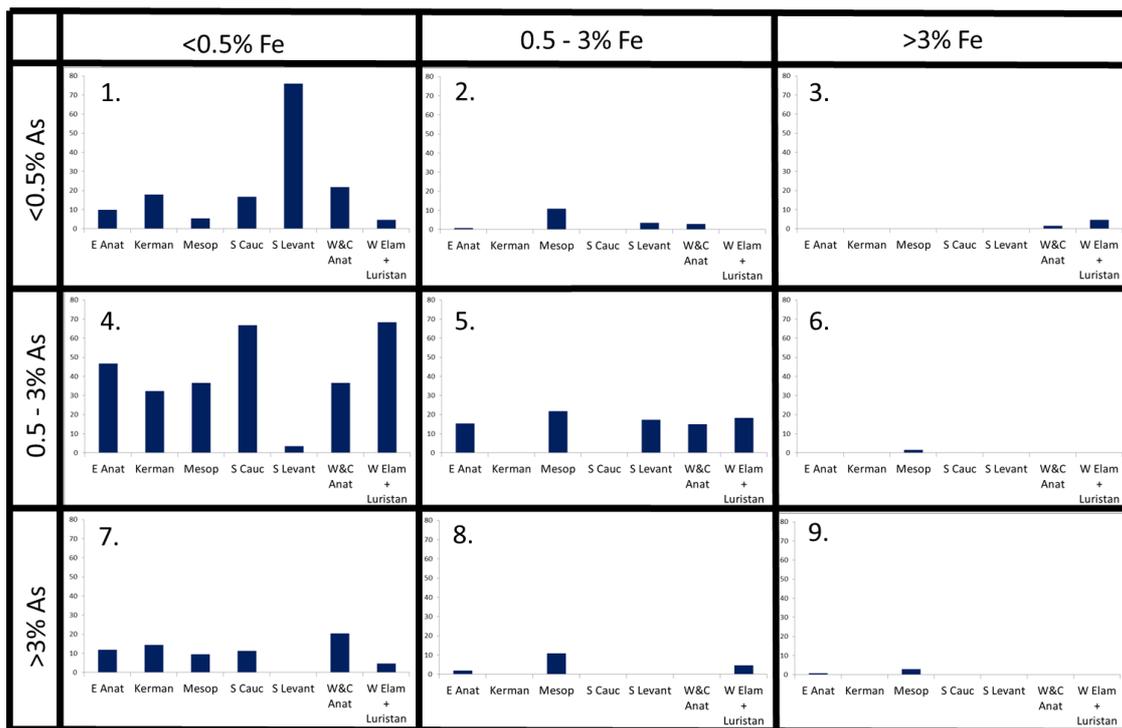


Figure 123: early 3rd millennium BCE copper-base assemblages from E Anatolia, plus two objects from Mersin (n=163); Kerman (n=28), Mesopotamia and two objects from Northern Mesopotamia (n=74); Southern Caucasus (n=18); Southern Levant (n=19); West and Central Anatolia (n=74); and Western Elam and Luristan combined (n=22).

In the early 3rd millennium BCE, significant portions of most regional assemblages were spread across the nine groups, though a smaller percentage of the objects contained >3% Fe (Figure 123). The majority of each assemblage was represented in squares one and four (<0.5% Fe, and <3% As), a lesser but still significant portion are represented by <0.5% Fe, and >3% As. None of these groups can represent the addition of speiss as they all contain <0.5% iron, difficult to achieve in the removal of iron once it is present in the composition. The copper is therefore

more likely to have been produced by smelting of arsenic-rich ore. The next group of compositions (square 5: 0.5% - 3% Fe and As) are the most ubiquitous after the initial three. There is sufficient iron for the potential addition of speiss, as 0.5 to 3% Fe is an achievable level after refining by oxidising the iron present in the copper. However, arsenic at <3% is not enough to affect the behavioural or aesthetic properties of copper (Kuijpers 2017; Mödlinger *et al.* 2017). If the *intention* of adding speiss was to control the arsenic content or produce a recognisably different material, we might expect to see more perceptible levels of the alloying element present in the resultant copper. Loss through later recycling and reheating is a possibility, however as can be seen from squares 8 and 9, there are not necessarily significant enough quantities of copper with >0.5% iron and >3% arsenic to support the theory of Southwest Asia wide addition of speiss to copper smelts with the purpose of creating arsenical-bronze.

As a comparison Figure 124 shows the same categories for the assemblages of the early 1st millennium BCE. Fewer objects contain high arsenic at this time, but iron at >0.5% is still present. This again would rather indicate a change of ores and the continued addition of iron as a consequence of the smelting tradition. These are of course very simplistic and preliminary studies, however alongside a lack of evidence for ferrous speiss across Southwest Asia (except in Iran) the results could indicate that the addition of speiss was not a widespread practice. The examples of copper that do contain >0.5% Fe and >3% arsenic could be indicative of copper traded from regions of Iran where the addition of speiss was routine, such as Arisman. Of course, this conclusion is also based on the assumption that the arsenic was added with the *intention* of affecting behavioural properties or colour

of object. It is entirely possible that speiss was added for reasons other than the creation of recognisable arsenical-bronze, such as the utilisation of useful secondary products from iron smelting (Thornton *et al.* 2009, p.309). In this case any category containing >0.5% iron (squares 3, 5, 6, 8, and 9) could indicate the addition of speiss to copper.

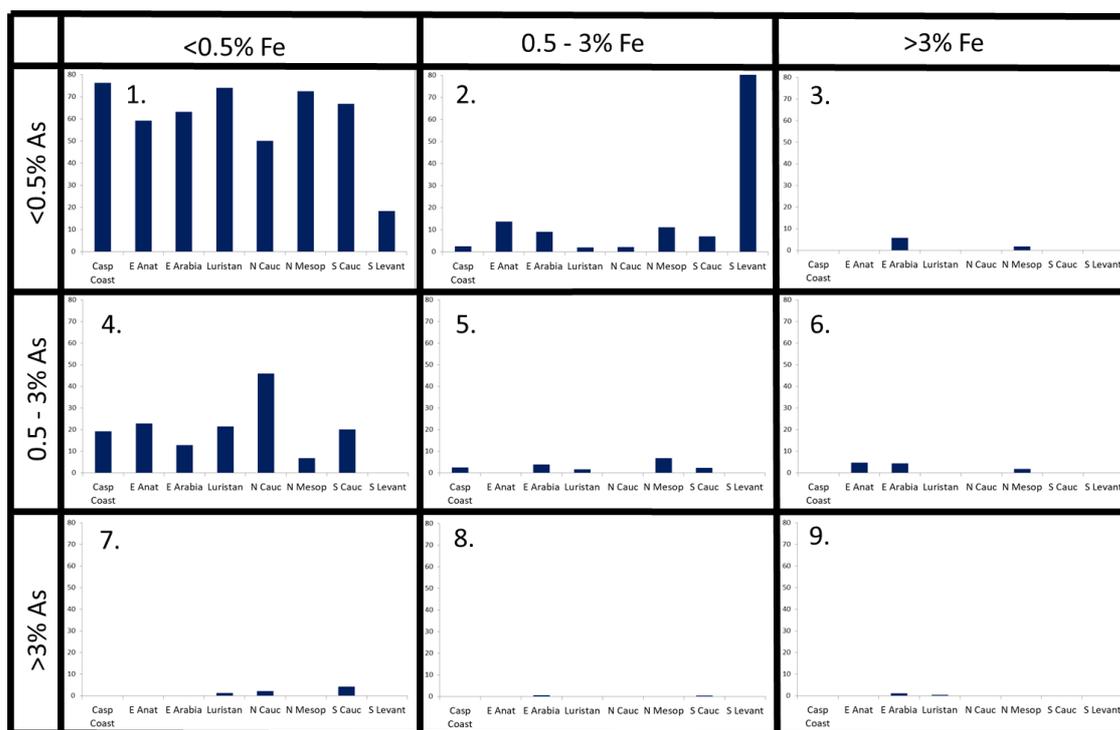


Figure 124: early 1st millennium BCE copper-base assemblages from the Caspian Coast (n=42) E Anatolia (n=22); E Arabia (n=211); Luristan (n=272); Northern Caucasus (n= 48); Northern Mesopotamia plus five objects from Mesopotamia (n=119); Southern Caucasus (n=18); and the Southern Levant (n=19)).

To summarise, the high levels of iron in copper from the 3rd millennium BCE onwards (and intermittently earlier) present interesting avenues of research. Trade appears to have occurred in iron-rich copper form despite its perceived lack of quality, but this material does not always appear to have had iron refined out before use. In the late 3rd millennium BCE the Mesopotamian craftspeople had access to iron-rich copper but applied it equally across object typology, and even in

vessels which would have required hammering. This could indicate that iron was not detrimental to copper, or perhaps says something about the organisation of copper distribution amongst workshops. With regards to ferrous speiss, it could certainly have been used, but through this preliminary research does not appear to have been the predominant technique for the production of arsenical bronzes in Southwest Asia. This is not to say it did not occur in periods later than the early 3rd millennium BCE. It is also based on the assumed intention of producing arsenical-bronze, however the addition of speiss could have occurred for other reasons than the enrichment of arsenic to perceptible levels, in which case all objects containing >0.5% As and some arsenic could represent copper that has had speiss added to it.

8.2 *Zinc-rich copper*

The final copper alloy that requires a small amount of discussion, though a full investigation is beyond the scope of this thesis, is zinc-rich copper. Intentionally fabricated early 'true brass' (>8% Zn) in the archaeological record has often been treated with scepticism, despite the fact that zinc ores are frequently found associated with copper ores (Thornton and Ehlers 2003). The main reason for this is the difficulty of creating a copper-zinc alloy owing to the volatility of metallic zinc which vaporises at 906° C (Pollard and Heron 2008, p.197). However should all objects containing >1% Zn therefore be dismissed simply because 8% zinc was not often achieved? Before going on to focus on the numerous examples of zinc-rich (1 – 8% Zn) copper in the archaeological record, there is a brief discussion about 'brass' (>8% Zn) from the mid-3rd to early 1st millennium BCE.

Number of zinc-rich (1 - 8% Zn) copper objects over time

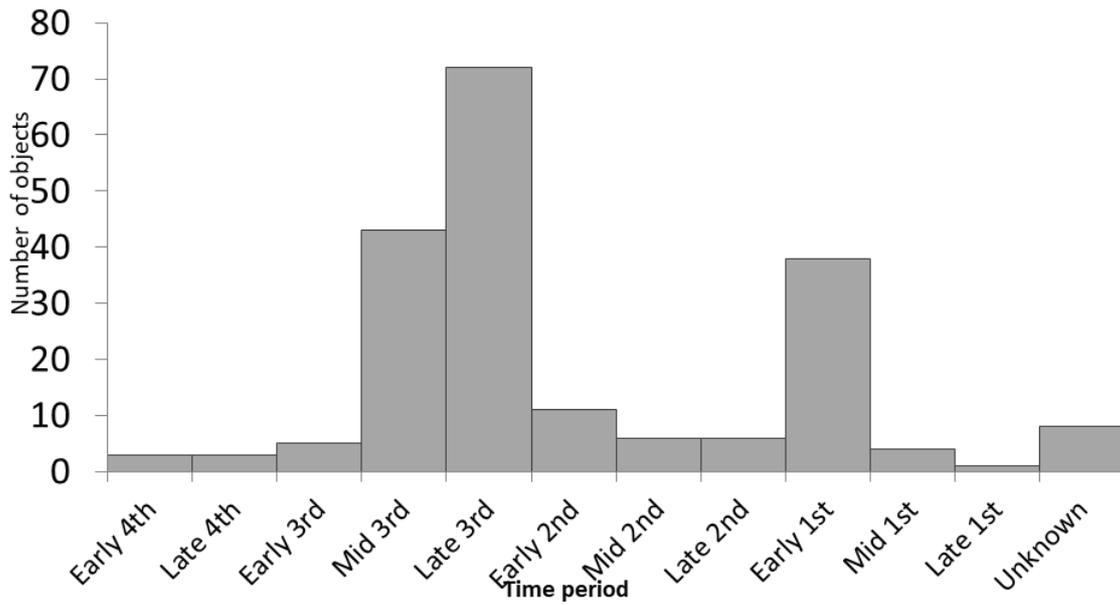


Figure 125: Number of zinc-rich (1 - 8% Zn) copper from each time period from Southwest Asia

Number of 'brass' (> 8% Zn) objects over time

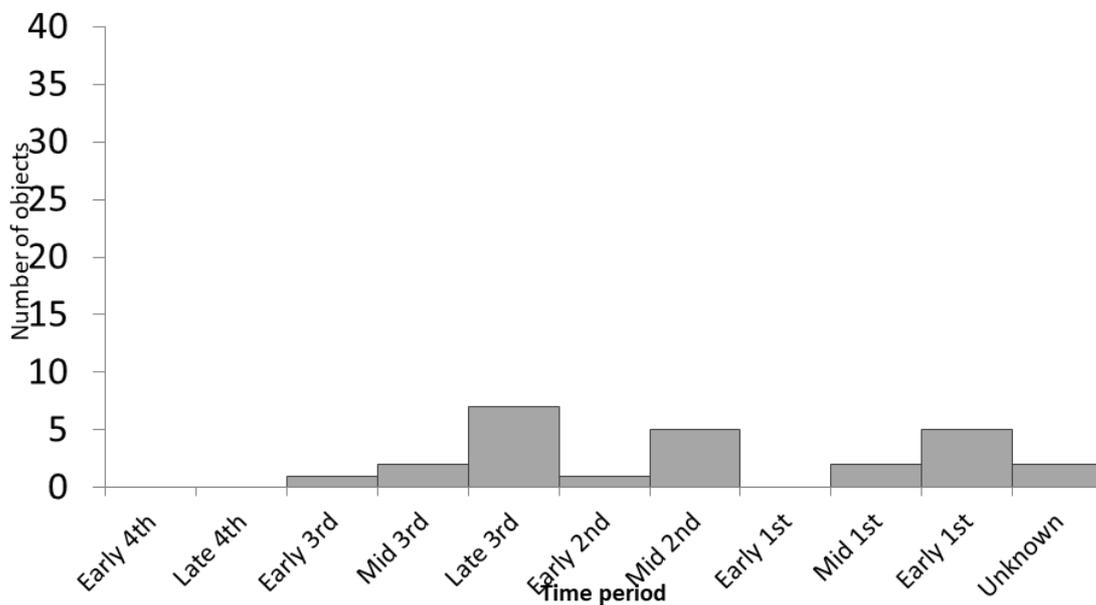


Figure 126: Number of 'brass' (>8% Zn) objects from each time period in Southwest Asia

Thornton and Ehlers (2003) state that zinc contents above 12% would have been sufficient to change the colour of the copper alloy. Two thirds of the twenty-one

'brass' (>8% Zn) objects would therefore have been a noticeably different material. In Thornton (2007) it is stated that 6 to 8% Zn would be sufficient to affect the properties of copper, although it is also stated that these could not be considered intentional alloys, merely serendipitous. On the other hand just because they were serendipitously smelted does not mean that they were not deliberately used.

Of the twenty-one 'brass' objects (>8% Zn), three were 'billets' or 'bars', two were unidentified objects, and the rest were high status objects such as figurines, belt-plaques, jewellery, and vessels, or weapons. The same is the true for the six objects containing 6 – 8% Zn: one 'bar', two plaques, a pin, a vessel, and a dagger. If 'bar' is correctly interpreted as some form of ingot, then this 'unintentional alloy' was still formed into an object for use by metalsmiths. From this scanty evidence there does not seem to be much difference in the way these zinc-rich alloys were used, whether intentionally smelted or not, which at the very least may point to a recognition of the material.

The samples are too disparate across both space and time to say much more about copper containing enough zinc to be recognisable to ancient craftspeople as outlined by Thornton (2007). However there are relatively frequent occurrences of copper containing 1 – 6% zinc which may still reveal aspects about ores and techniques used, even if they were not recognised by the craftsman. The process of *cementation* is traditionally regarded as the only technique by which 'brass' (>8% Zn, though normally nearer 30% Zn) can be achieved. What is necessary is a sealed or closed crucible in order to limit the volatilised zinc escaping from the mix. After a certain temperature is achieved the zinc gas remaining in the crucible is absorbed uniformly into the copper, in much the same process as avoiding the

loss of arsenic in a smelt (Pollard, *personal communication*). Zinc contents between 1 and 8% could indicate either a sealed, or at least partially covered, crucible containing the relevant ore sources. This in and of itself could therefore indicate aspects about regional smelting technology: whether the regional tradition involves sealed environments or open crucibles.

The presence of zinc in regional copper assemblages may also indicate the ore in use at that time. The copper containing 1 – 6% Zn will therefore be studied in relation to how frequently it is associated with other elements, as this may indicate the smelting of polymetallic ores or the smelting of a combination of ores. In order to minimize the temporal and geographical scatter only 3rd millennium BCE objects will be looked at, most of which are from the Southern Caucasus or Mesopotamia.

Copper objects containing 1 – 6% zinc are frequently also alloyed with other elements, or a combination of other elements (Figure 127). The most common zinc-rich alloy from the 3rd millennium is zinc-tin-copper, which makes up almost a third of the entire zinc-rich assemblage. There has been a noted correlation between the appearance of zinc and tin in both at Tepe Yahya in Iran and Umm an-Nar in Eastern Arabia (Thornton 2007). These sites are not represented in this assemblage, but the link between the two elements is. It is suggested that these alloys may have been made by recycling scrap metal or the use of polymetallic ore sources (Thornton and Ehlers 2003; Thornton 2007). The fact that there are fewer zinc-only copper alloys than zinc-rich-complex alloys may indicate the use of polymetallic ores.

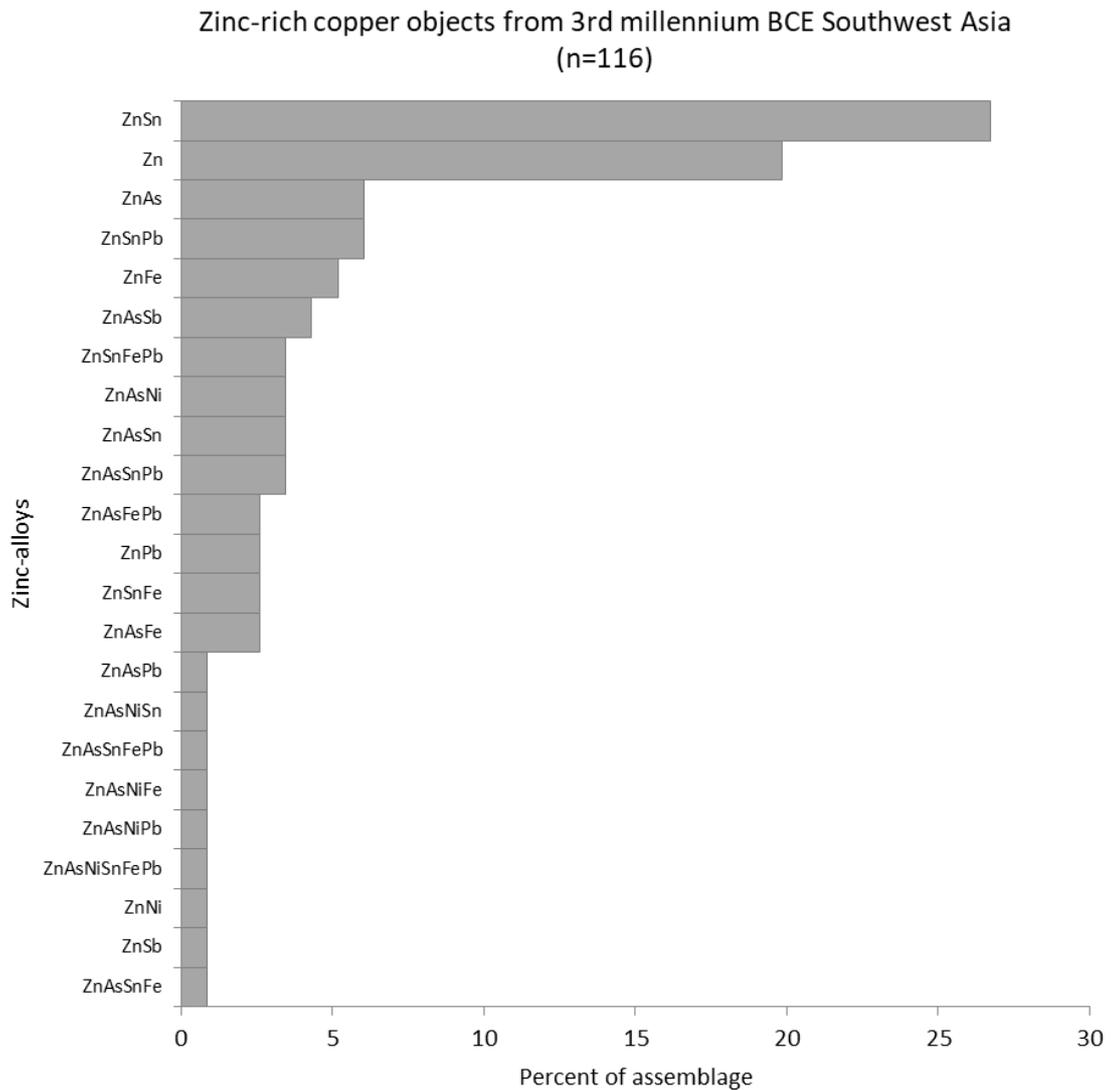


Figure 127: assemblage of 3rd millennium BCE zinc-rich copper (1 – 6% Zn) from Southwest Asia containing alloying levels (>1%) of other elements

As with the iron-rich copper discussion, these are simplistic preliminary methods for looking at the material and no firm conclusions can be based on them. However they are an indication that the discussion of zinc should move beyond the deliberation with which it was smelted as there are numerous occurrences of zinc-rich copper throughout time. If intentionality of smelting zinc-rich copper is studied, it would be interesting to know the cumulative effects of alloying element combinations on the behavioural and aesthetic qualities of copper. Further

research into open and closed crucible smelting and the effects it had on copper compositions would also be beneficial.

9 Chapter summary

To summarise, the four most significant findings of this chapter will be presented. Though the earliest secure date for the beginning of smelting is in the 5th millennium BCE, this should not be considered as the moment when smelting technology was actually developed. There is some ambiguity between native copper and early smelted material, however there are significant, if scattered and less securely dated, examples of early material for three millennia preceding the 5th millennium BCE. It is possible that small-scale and regional experimentation in exploitation was occurring, as well as a developing interest in metallic objects. This experimentation was carried through into early alloying which did not develop as a separate step but which was evident from the beginning of copper use. This experimentation appears to have included working with tin ores in some form. With several tin-bronzes belonging to the 4th millennium BCE, it can no longer be considered a 3rd millennium development, though it was not until the mid-3rd millennium BCE that a proper and possibly separate tin-bronze tradition was adopted across Southwest Asia.

The Kestel mine is not supported as a large-scale exporter of tin to Southwest Asia in the 3rd millennium BCE by the available tin-bronze data. In the early 3rd millennium BCE, even the West and Central Anatolian tin-bronze assemblage does

not support local, regional use of the mine. This is not the case in the mid- and late-3rd millennium BCE, as the regional tin-bronze data could support Kestel supplying tin north of the Taurus Mountains. Tin-bronze use from the Mediterranean region to Mesopotamia does not bolster the concept of tin travelling from the Taurus Mountains to the rest of Southwest Asia. It is therefore unlikely, if it was possible to exploit Kestel for tin, that it was a major tin supply.

In the early 1st millennium BCE there was a radical change in copper and tin-bronze traditions after the collapse of the Bronze Age and its accompanying trading network. Tin-bronze became the dominant alloy in use, suggesting more stable access to the resource, and copper-alloying practices became less variable. There was a specific level of unity in the region from Eastern Anatolia, the Southern Caucasus, Northern Mesopotamia, and Northwest Iran. The outliers such as the Northern Caucasus and Eastern Arabia which had been less effected by the collapse of the Bronze Age, display more continuity to the 2nd millennium BCE traditions. Finally, though iron- and zinc-rich copper are not, or have not been treated as, traditional alloys, they are in fact great sources of information regarding ore choice, technological approach, and possibly the organisation of regional metalworking industry.

Chapter Six: Large Scale Synthesis

This chapter builds on the results of the standard systematic treatment of data from each study region, as presented in Chapter Four, to correlate emerging patterns and explore the apparent flow of materials, practices and preferences at a supra-regional scale. In this, the general ethos of the research remains very close to that of the architects of the 'Oxford System', nevertheless, the scale of the database, the highly variable and uneven character of archaeometallurgical research in the region, and the specific challenges of early metallurgical practices in southwestern Asia (see Chapters Two and Three) required a move beyond the standard approach and a fuller focus on aspects of the methods that have, thus far, been relatively peripheral and rarely used except in very specific local contexts.

The first section of this chapter deals specifically with the flow of copper with regard to three copper groups, the methodology of which is outlined in Chapter Three, section 4. There is then a discussion on the effectiveness of this method when applied to such varied regions of research and over such time period. The second section is a further application of the Oxford System but within more confined parameters, the aim of which is to ascertain in what form (tin/tin-ore vs

ready-made tin-bronze) tin was traded throughout Southwest Asia, and any visible changes from the copper group pattern.

1 Patterns of copper use in Southwest Asia

1.1 Application of 'Oxford System' for trace elements

As discussed fully in Chapter Three, the copper groups are assigned to one of sixteen categories by the presence or absence of arsenic, antimony, silver, and nickel. The ubiquity of these groups within the regional and temporal assemblage is then calculated. The regional ubiquity of these groups has then been compared across Southwest Asia and from the late 4th millennium to the early 1st millennium BCE. The aim is to assess changes or continuity in the pattern as it unfolds. Owing to the large number of influences on copper group– such as intentional alloying and intense trade across Southwest Asia – if all the copper signals are viewed at once the pattern is unwieldy and becomes a mechanism for simply churning out more diagrams, rather than understanding the flow of copper that they represent. Three copper groups have therefore been isolated and the percentages of their use in regional and temporal assemblages are presented below. As there is no way of easily indicating the number of objects in each assemblage, and the assemblages vary in size dramatically, no assemblage has been retained that contains less than twenty objects.

The three copper groups chosen are 'arsenic-only' copper (group 2), 'arsenic-antimony' (group 6), and 'arsenic-nickel' (group 11). Arsenic-only copper is studied owing to its ubiquity throughout the Bronze Age across Southwest Asia,

and the many arsenic-rich minerals across Southwest Asia which are frequently associated with malachite (Rapp 2002), arsenic-antimony copper due to the higher instance of antimony in objects in the Caucasus (Pike 2002) and arsenic-nickel owing to its contextual importance relating to the copper of Magan which was traded widely (Begemann *et al.* 2010).

Table 28 The percent of each regional assemblage made of arsenic-only copper (>0.1% As). Key: orange for percentages between 20% and 40%, and red for percentages greater than 40%.

As-only	W&C Anatolia	Med Coast	E Anat	S Cauc	N Cauc	Cyprus	S Levant	N Mesop	Mesop	W Elam	Luristan	Caspian Coast	Kerman	Eastern Arabia
Late 4th	57%		33%	3%	57%			28%		0%		60%		
Early 3rd	7%		21%				21%		40%				47%	
Mid 3rd	45%	20%	33%	35%	84%	32%	25%	28%	40%	11%	13%		46%	9%
Late 3rd	45%	21%		48%	76%	65%	33%	4%	11%	7%	17%	32%	46%	7%
Early 2nd		46%		57%		57%	23%	22%	16%	0%	20%	45%		7%
Mid 2nd	42%	43%	24%	27%	41%	56%	40%			11%	26%	29%	34%	13%
Late 2nd				38%	11%	46%	49%			0%	55%	29%		14%
Early 1st			9%	22%	21%		18%	32%			30%	31%		12%

Table 28 highlights how prevalent arsenic was in copper throughout the Bronze Age, but also possibly indicates where the rough source regions are. West and Central Anatolia and the Caucasus show a strong signal of arsenic-only copper, as does the Caspian Sea Coastal region, Kerman, and Cyprus. The Cypriot signal is interesting, as arsenic-only copper increases dramatically from the mid-3rd to the late 3rd millennium BCE, though the earliest evidence of smelting technology is only dated to the mid-2nd millennium BCE (Knapp *et al.* 2001, p.205).

As a tool for regional comparison, simply looking at the pattern of arsenic-only copper is not sufficient. Here we turn to arsenic-antimony (Table 29) where the pattern of use is vastly different. Arsenic-antimony copper is clearly not as widespread as arsenic-only copper, but more than that it shows clear grouping of use around the Caucasus and only very sporadic use elsewhere. In the early 1st millennium BCE, after barely any encounters with this copper type, the Eastern Anatolian assemblage predominantly comprises arsenic-antimony copper.

Furthermore, arsenic-antimony copper amounts to two-thirds of the tin-bronze assemblage and is not present without the addition of tin (though there are only 3 non-tin bronzes in the assemblage at this time). During the early 1st millennium BCE Eastern Anatolia was the location of the Urartian Kingdom, which had close cultural contacts with the Southern Caucasus, Northern Mesopotamia, and Northwest Iran (Castelluccia 2017b; Castelluccia and Dan 2014; Danti 2013; Dan 2010; Barnett 1982). This sudden increase in the ‘arsenic-antimony’ copper group therefore represents better access to the antimony-rich ores of the Caucasus. As such we might expect to see a similar increase in Northern Mesopotamia, Luristan, and the Caspian Coastal region. Increased use is only evident in Northern Mesopotamia.

Table 29: The percent of each regional assemblage made of arsenic-antimony copper (>0.1% As and Sb). Key: orange for percentages between 20% and 40%, and red for percentages greater than 40%.

AsSb	W&C Anatolia	Med Coast	E Anat	S Cauc	N Cauc	Cyprus	S Levant	N Mesop	Mesop	W Elam	Luristan	Caspian Coast	Kerman	Eastern Arabia
Late 4th	7%		3%	3%	0%					4%		6%		
Early 3rd	5%		6%				3%		4%	0%			3%	
Mid 3rd	10%		0%	17%	8%	0%	5%	20%	4%	2%	7%		5%	0%
Late 3rd	11%	19%		20%	0%	3%	9%	4%	3%	0%	6%	7%	3%	0%
Early 2nd		3%		8%		5%	0%	0%	4%	0%	5%	4%		0%
Mid 2nd	18%	14%	4%	37%	18%	11%	3%			0%	13%	0%	6%	0%
Late 2nd				23%	8%	4%	5%			0%	3%	5%		0%
Early 1st			59%	20%	40%		0%	25%			6%	8%		1%

If we compare the ‘arsenic-antimony’ copper signal with that of arsenic-nickel copper (Table 30), we can see a much heavier density of the latter in the southeastern region of Southwest Asia, with the strongest signal of ‘arsenic-nickel’ copper coming from Eastern Arabia. As mentioned in Chapters Two and Five, the Omani copper sources are known for high levels of nickel and arsenic (Begemann *et al.* 2010; Weeks 2003). However copper minerals containing arsenic and nickel

are also known from the highlands of Anatolia and the Caucasus, so the signal cannot be seen as exclusive indication of trade from the Persian Gulf (Chernykh 2017a; 2017b; 1992). There are several nickel arsenides (e.g. orcelite¹¹, maucherite¹², and nickeline¹³) which are often found associated with chalcopyrite (Mindat.org 2018). Minerals containing arsenic or nickel, and occasionally both (i.e. annabergite¹⁴), are also found in Western Asia in oxidised zones containing malachite (Rapp 2002). These ores could therefore have easily been smelted accidentally, or perhaps were actively sought and enriched.

Table 30: The percent of each regional assemblage made of arsenic-nickel copper (>0.1% As and Ni). Key: orange for percentages between 20% and 40%, and red for percentages greater than 40%.

AsNi	W&C Anatolia	Med Coast	E Anat	S Cauc	N Cauc	Cyprus	S Levant	N Mesop	Mesop	W Elam	Luristan	Caspian Coast	Kerman	Eastern Arabia
Late 4th	9%		23%	3%	33%					21%		4%		
Early 3rd	4%		27%				0%		14%				9%	
Mid 3rd	10%	23%	0%	3%	2%	10%	3%	14%	18%	43%	16%		5%	49%
Late 3rd	20%	21%		5%	12%	9%	2%	34%	34%	14%	25%	2%	25%	44%
Early 2nd		3%		7%		1%	0%	31%	49%	32%	32%	15%		57%
Mid 2nd	22%	14%	16%	5%	10%	0%	4%			51%	26%	0%	31%	55%
Late 2nd			3%	5%		35%	5%			0%	10%	0%		49%
Early 1st			0%	2%	6%		9%	2%			16%	0%		54%

1.2 Assessment of the 'Oxford System' for trace elements

Though the Oxford System for trace elements is a useful diagnostic tool, it is less easily applied to large, complex, and irregular collations of assemblages. With prior knowledge of minerals and ores accessible to certain regions some patterns can be assessed, but there are too many external influences to isolate each cause. The many variables in the web of inter-regional contact in Southwest Asia is such that

¹¹ Orcelite: Ni_{5-x}As₂x

¹² Maucherite: Ni₁₁As₈

¹³ Nickeline: NiAs

¹⁴ Annabergite: Ni₃(AsO₄)

changes in pattern cannot easily be ascribed to either change in ore source, or patterns of recycling and re-use. Discussion of these copper groups has therefore necessarily turned towards provenance as only sweeping patterns are visible at such a scale. However one of the express aims of the Oxford System is to move away from provenancing and instead shift focus to the people behind the technology.

At a closer scale the copper combinations can be researched alongside information about object type but owing to the diversity of typology over such large distances these cannot be easily compared for the purposes of this research, and a specific cultural context is necessary to provide any meaning. The following section will highlight how this methodology can be used successfully if the specific aims of the exercise are set within narrower parameters.

2 Trace element compositions in tin-bronzes

The above exercise in applying the Oxford System for trace elements indiscriminately to all copper-based objects is useful as an indication for hotspots of certain copper compositions and their subsequent flow, however to access information about human activity it is necessary to apply extra parameters. The next step was therefore to define an aspect of copper metallurgy clearly influenced

by intentional human activity that is applicable and only answerable via large-scale data comparison.

The rarity of tin ore in Southwest Asia provides us with a useful starting point. Though unintentional alloying of tin-bronze from weathered products of sulphide ores such as stannite is a possibility, it is only so in small quantities and with variable tin contents due to the mineralogical scarceness. It is well accepted that tin must have been supplied to Bronze Age Southwest Asia from outside, in which case we know that trade in tin is being *actively* conducted by local inhabitants. The source, whether in Anatolia, Afghanistan, Luristan, Cornwall, or a combination of all, is immaterial (Cuénod 2013; Muhly 1985; Yener 2000). The point of this is not to ascertain where tin was coming from, but how and in what form. Was it traded as tin (either in ore form or metallic) or was it transported as pre-alloyed tin-bronze? Are the variations in copper type an indication of the source of tin, or of imported tin being added to local copper? Was tin traded to one region and then actively traded on, or were the original traders responsible for bringing the material to each region individually? The system of tin trade is unlikely to have been consistent over two millennia.

There are examples of tin ingots in antiquity: tin-oxide remains of tin ingots were found on the Late Bronze Age shipwreck at Cape Gelidonya (Bass 2012); 120 tin ingots were found on the LBA Uluburun shipwreck (Hauptmann *et al.* 2002); and two tin ingots were found near the coast in Israel (Maddin *et al.* 1977). There is even evidence of the occasional Bronze Age tin object suggesting that metallic tin was known in antiquity (*ibid.*). Metallic tin does not survive very well in certain temperatures because it is susceptible to 'tin-pest': the allotropic transformation of

metallic tin into 'grey tin' powder, which occurs at $\sim 13^{\circ}\text{C}$. This modification may be the cause of the relative lack of archaeologically discovered metallic tin objects and ingots (*ibid.*). Tin could also have been traded in ore form, though very few instances of cassiterite have been found at the relevant sites. There are several possible reasons for this lack of excavated cassiterite: firstly, that none have been recovered in archaeological contexts though they do exist; secondly, owing to the value of cassiterite any samples were smelted if and when they were found; or thirdly, tin ore was smelted into metallic tin before being traded.

The question of how tin was traded (in ore/metallic form vs. as ready-made tin-bronze) is an appropriate research question for the application of the Oxford System for trace elements. There is now a defined set of parameters as well as a question which directly involves human activity and human approach to the material. Trends across such a large dataset can also be taken as more reliable, as the abundance of data and repetition over numerous regions will reinforce any patterns present rather than obfuscate them.

This approach was carried out by comparing the copper groups of tin-bronze assemblages with those of non-tin copper assemblages in each region from the mid-3rd millennium BCE onwards. (NB. This starting point was chosen owing to the sporadic nature of tin-bronze use in preceding periods). The hypothesis is that if tin was traded as pre-alloyed tin-bronze we might expect to see a certain copper group (or regularly occurring patterns of copper groups) associated with tin. If the copper groups of tin-bronze objects and copper-only objects match, we could suppose that tin was added to locally available copper, suggesting the import of tin in metallic or ore-form rather than as ready-made tin-bronze.

The following sections display comparisons between the untinned copper assemblages and tin-bronze assemblages in a selection of regions from the mid-3rd millennium BCE and early 2nd millennium BCE. These two periods were chosen because they represent different phases of inter-regional communication: the mid-3rd millennium BCE witnessed the Southwest Asian-wide adoption of tin-bronze, which implies a level of uniformity in trade; the early 2nd millennium BCE was a period of economic recovery following the collapse of inter-regional trade at the turn of the millennium. Access to commodities such as tin would surely have varied between these two periods and ought to have had a visible effect on regional approaches to tin-bronze production. The tin-bronze copper compositions that match what we might tentatively call the 'local' copper signal are highlighted in yellow, those which do not match the untinned ('local') copper are highlighted in blue.

2.1 Mid-3rd millennium BCE tin-bronze and 'local' copper signals

A sweeping glance of Figure 128 highlights the fact that the regional tin-bronze assemblages generally match the 'local' copper in use. Only small percentages of tin-bronzes in West and Central Anatolia, Luristan, and Mesopotamia do not match that signal. These additional copper groups represented by tin-bronzes are not uniform, therefore it is possible to infer that they do not represent pre-alloyed tin-bronze produced by a production region that then exported its products widely to

Southwest Asia. Instead these tin-bronzes may reflect inter-regional trade of finished artefacts on a smaller, more sporadic scale.

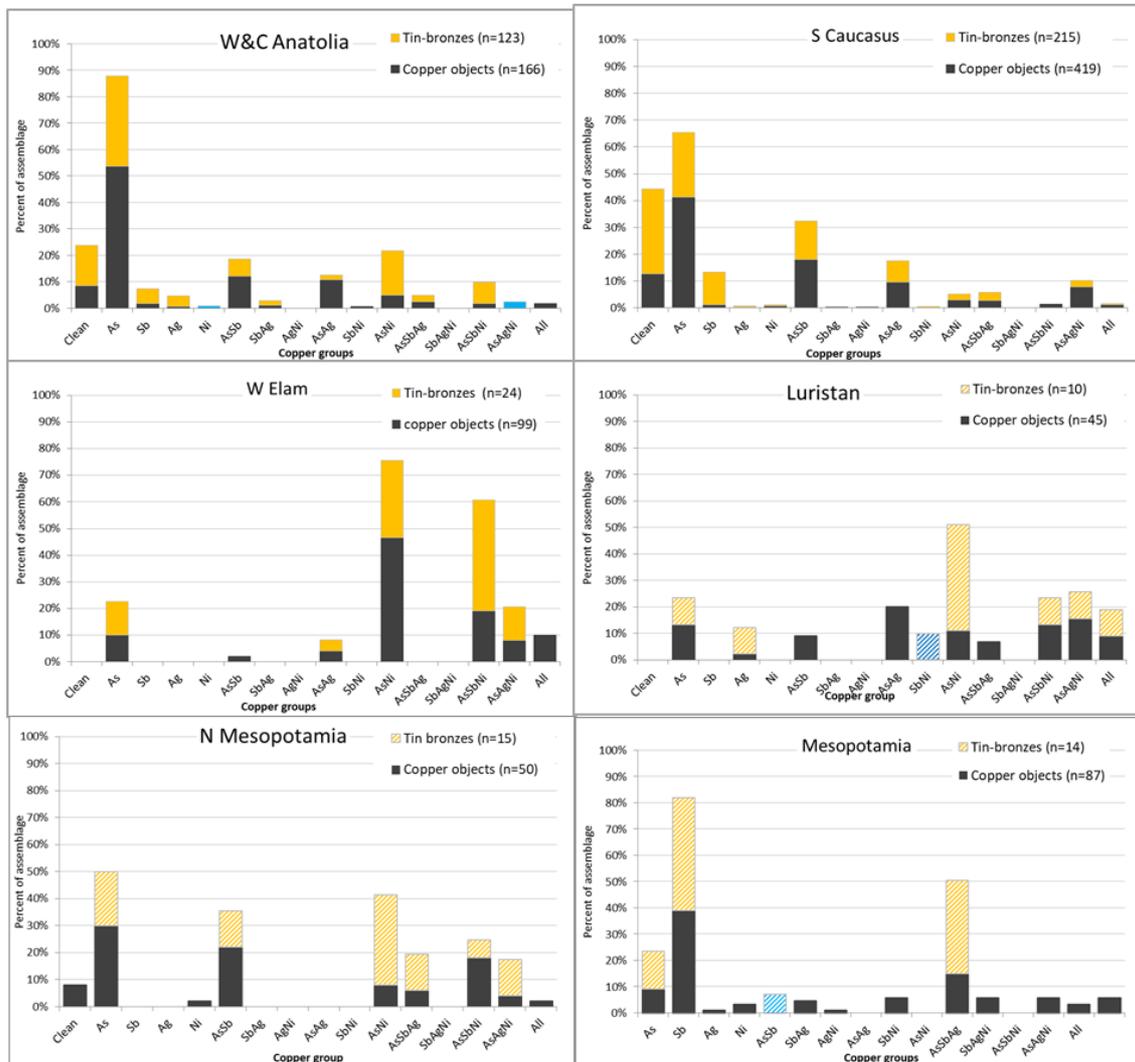


Figure 128: mid 3rd millennium BCE regional tin-bronze and untinned copper assemblages, and the ubiquity of copper groups within these assemblages

The assemblages from West and Central Anatolia, Southern Caucasus, Western Elam, and Northern Mesopotamia display patterns of tin added to an entire regional tradition, as it appears uniformly across the entire untinned assemblage. This may indicate something about the nature of organisation: if tin was traded only to centrally organised production centres we might expect a more limited

range of copper groups in use owing to the established source of ore within that tradition. The lack of this however may indicate that tin was uniformly accessible across each region.

AsNi copper (copper group 11) poses more limitations within its interpretation. We know that it was mostly (though not exclusively) traded from Magan which also had access to tin. If AsNi was only visible in tin-bronze assemblages it would be clear that it was traded pre-fabricated and produced in Eastern Arabia. However we see a very consistent pattern of both AsNi untinned copper *and* AsNi tin-bronze. Both materials therefore could be being traded alongside one another, but separately before being mixed at the destination location, or AsNi tin-bronze *and* AsNi untinned copper could be being synchronously traded. More than the mere presence of the copper group therefore needs to be investigated. See section 3.1 in this chapter for further discussion.

In summary, overall it would appear that in the mid-3rd millennium BCE tin was traded either in metallic or ore form across Southwest Asia and being independently added to local copper. Some pre-alloyed tin-bronzes may have been traded as part of inter-regional trade but conducted between specific regions rather than occurring across a widespread system. It might also be possible to infer an intra-regionally homogenous access to tin, owing to the uniformity with which it appears to be added to all available copper, rather than copper with a specific composition which might indicate regionally centralised control.

2.2 Early 2nd millennium BCE tin-bronze and 'local' copper signals

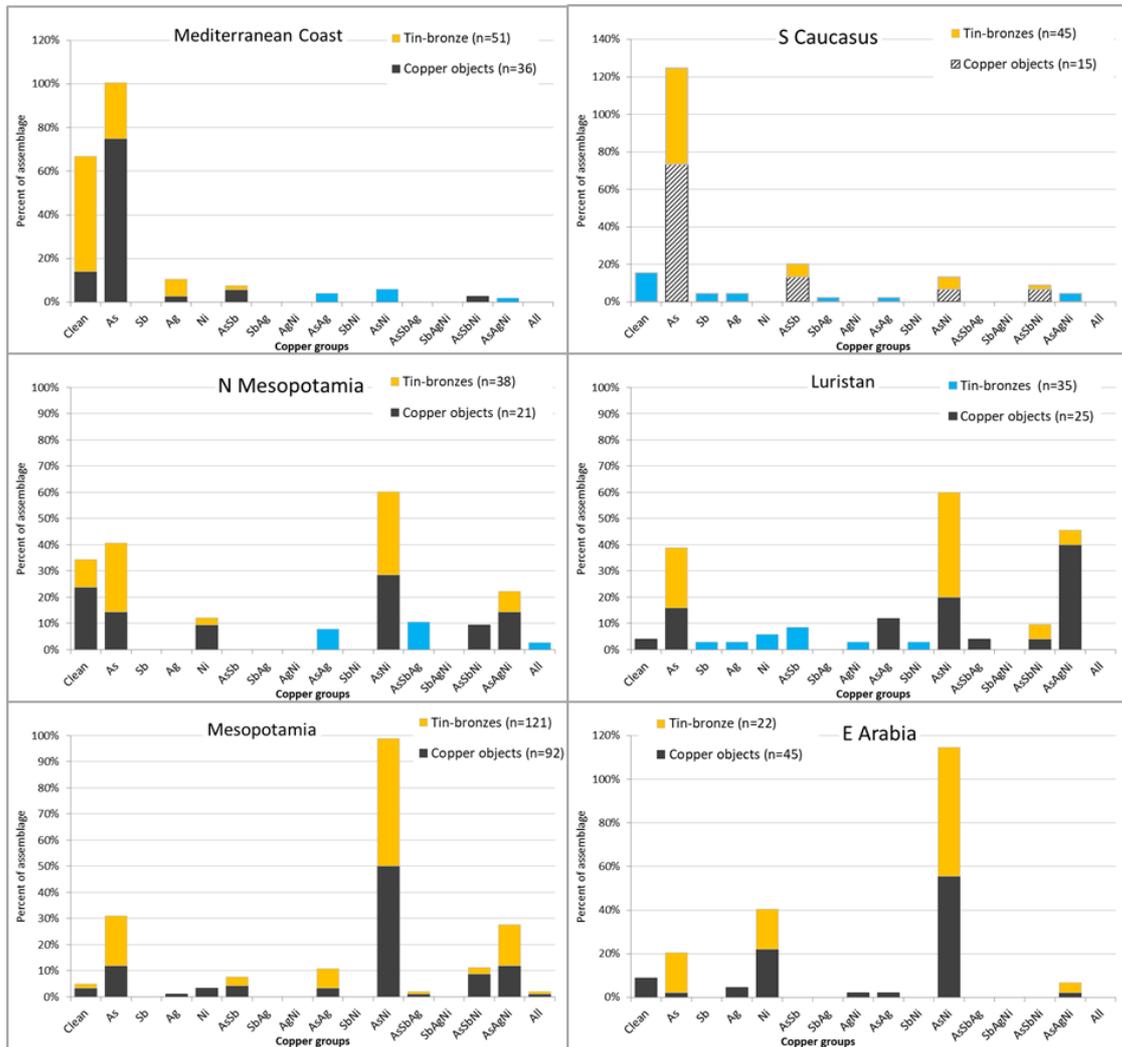


Figure 129: early 2nd millennium BCE regional tin-bronze and untinned copper assemblages, and the ubiquity of copper groups within these assemblages

The picture across Southwest Asia in the early 2nd millennium BCE is altered from that of the mid-3rd millennium BCE (Figure 129). Unfortunately the West and Central Anatolian assemblage is not large enough for comparison in this region and has been replaced with the Mediterranean Coastal region. Similarly Western Elam has been replaced with Eastern Arabia. Though these regions are obviously not interchangeable, they are located on the similar end of the northwest/southeast spectrum. The more northerly regions of Southwest Asia (the

Mediterranean Coast, Southern Caucasus, Northern Mesopotamia, and Luristan) have larger proportions of the tin-bronze assemblages represented by groups which are not present in the 'local' copper signal. The Southern regions (Mesopotamia and Eastern Arabia) match completely. In fact, though unreliable, it is worth noting that the single tin-bronze object from West and Central Anatolia is unrepresented in the untinned copper assemblage (only fifteen objects), and the seven Western Elam tin-bronzes are only composed of copper represented in the untinned copper assemblage (only twelve objects). These are referred to owing to their addition to the northern/southern split of matching and unmatching tin-bronzes.

After a period of relative inter-regional isolation, access to widely imported tin would likely have been interrupted. Trade in scrap tin-bronze may therefore have increased and formed a large part of the tin-bronze economy. The regions in which trade was less interrupted (and with a closer proximity to the hypothesised trade route) were apparently unaffected. It must be borne in mind, however, that Mesopotamia has no copper sources of its own, and therefore trade as pre-alloyed tin-bronze from Eastern Arabia is a viable possibility. The presence of copper groups in the Mesopotamian assemblage that are not also prominent in Eastern Arabia do indicate that *some* tin was imported and possibly in metallic/ore form as many of these groups are not simultaneously represented in neighbouring regions.

Another possible explanation for this alteration in tin-bronze copper composition may not wholly rely on access to tin: it is possible that after a widespread interruption in tin acquisition: regional traditions may have developed that *were* a direct reflection of this interruption, but once tin was widely traded again these

regional models of tin-bronze production could have continued alongside the former model of production. This would result in a less uniform approach to tin-bronze traditions across Southwest Asia. Interestingly, Luristan has often been thought to have tapped local tin sources in regional production (Cuénod 2013): though this may indeed have been occurring, it seems that in the early 2nd millennium BCE a contemporary tradition of tin-bronze imports or secondary production with scrap was also happening.

In summary, unlike the mid-3rd millennium BCE the regional traditions of the early 2nd millennium BCE seem to have become either more isolated or based on regional preferences, and trade in pre-alloyed tin-bronze appears to have increased (whether as scrap or primary tin-bronze). Mesopotamia, Eastern Arabia, and (to a tentative extent) Western Elam appear to have been unaffected by this alteration in economic model, possibly owing to their proximity to the Persian Gulf.

From the above examples it is generally possible to notice differences or similarities in regional copper composition as compared with the copper composition in the tin-bronze assemblage. These insights give an indication as to whether the region in question is importing tin-bronze objects from other regions or creating their own regional tin-bronze tradition. It is necessary to look at the spread of individual copper groups across Southwest Asia as a whole, however, in order to ascertain how tin was circulating inter-regionally. The continuous reoccurrence of certain copper compositions in tin-bronzes may go some way to explaining these avenues of communication and trade.

2.3 *Pan regional circulation of copper groups 2, 5, 6, 9, and 11*

A chronological series of bar charts (placed in the rough order of geographical location and referred to as 'data maps' from here on in) are presented in the following section. These bar charts report the ubiquity of copper groups in the regional untinned copper and tin-bronze assemblages. In order to present these assemblages so that chronological change can be easily visible, the 'data maps' themselves are fit two to a page. Detailed information on assemblage size is therefore lost, but for a larger copy of each of these 'data maps' see appendix A. For the ease of visualisation on a brief scale, regional tin-bronze assemblages with fewer than ten objects are present but have been faded out, and those with ten to twenty tin-bronzes are presented with cross hatching. As the emphasis of this section is on the tin-bronzes themselves, untinned copper assemblages with fewer than twenty objects are presented with cross-hatching to indicate the small sample size but none are faded. Copper groups are represented by different colours in order to roughly assess their ubiquity in regional assemblages over time: 2: As-only (blue), 5: Ni-only (yellow), 6: AsSb (green), 9: AsAg (pink), and 11: AsNi (also yellow). Ni-only and AsNi are both highlighted in yellow because they are linked with copper from Magan, Eastern Arabia (Begemann *et al.* 2010; Weeks 2003). The aim of the following representations is to allow for patterns of regional tradition and communication to be immediately visible, and as the size of the bar indicates the ubiquity of each individual group within the assemblage, the flow of that copper composition can possibly be inferred.

Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

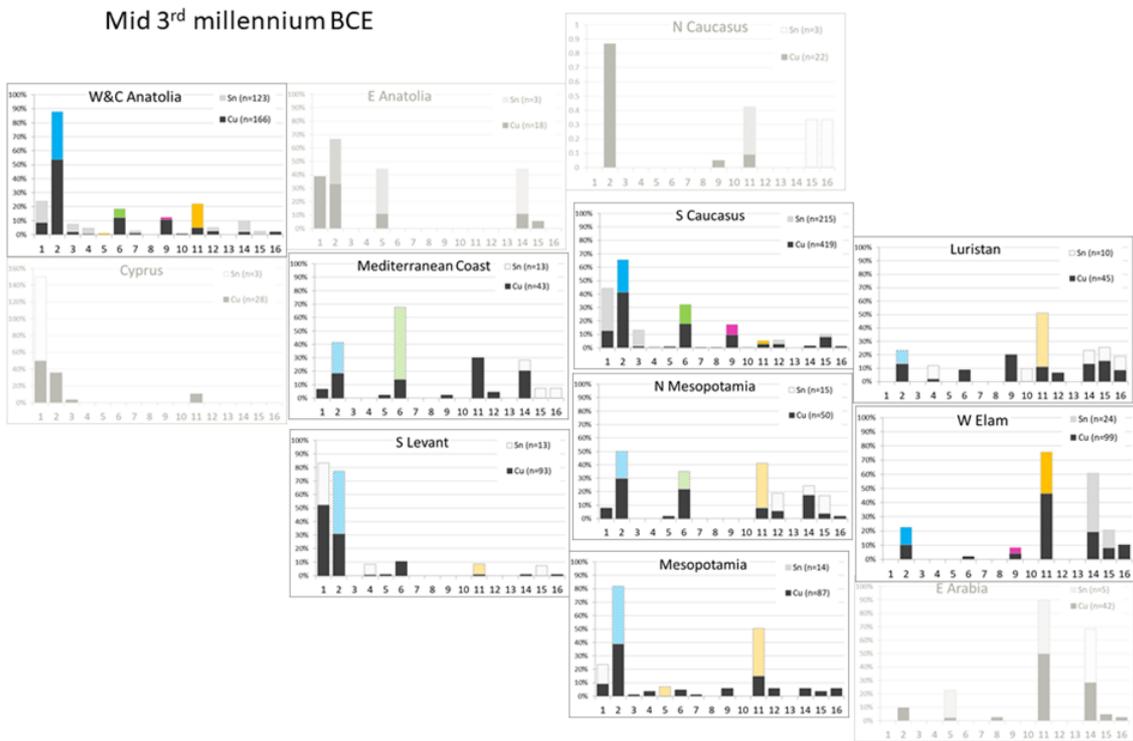


Figure 130: mid-3rd millennium BCE 'data map' of Southwest Asia presenting the ubiquity of copper groups in untinned copper and tin-bronze regional assemblages

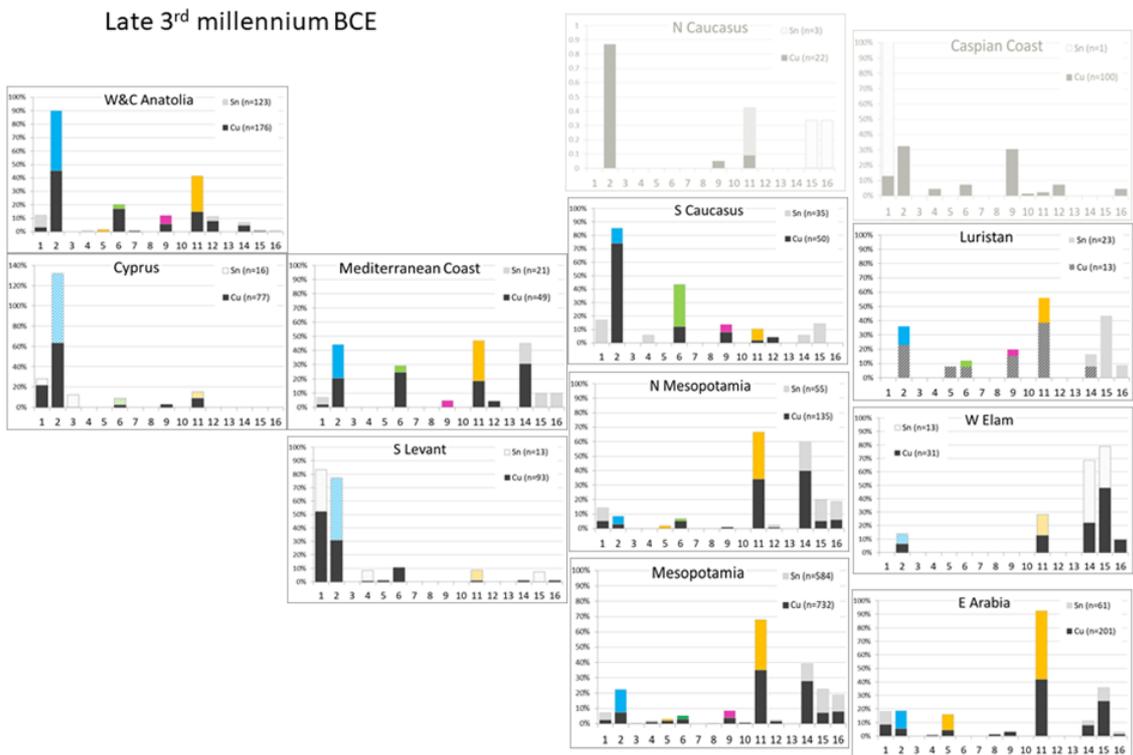


Figure 131: late 3rd millennium BCE 'data map' of Southwest Asia presenting the ubiquity of copper groups in untinned copper and tin-bronze regional assemblages

Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

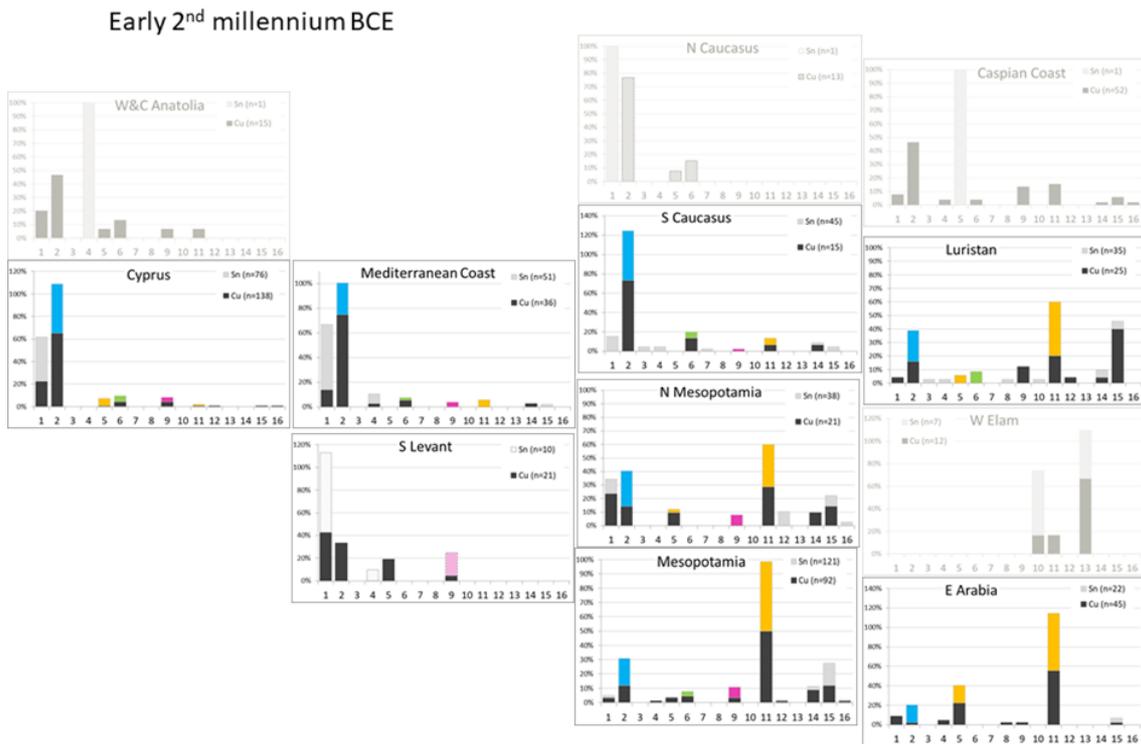


Figure 132: early 2nd millennium BCE 'data map' of Southwest Asia presenting the ubiquity of copper groups in untinned copper and tin-bronze regional assemblages

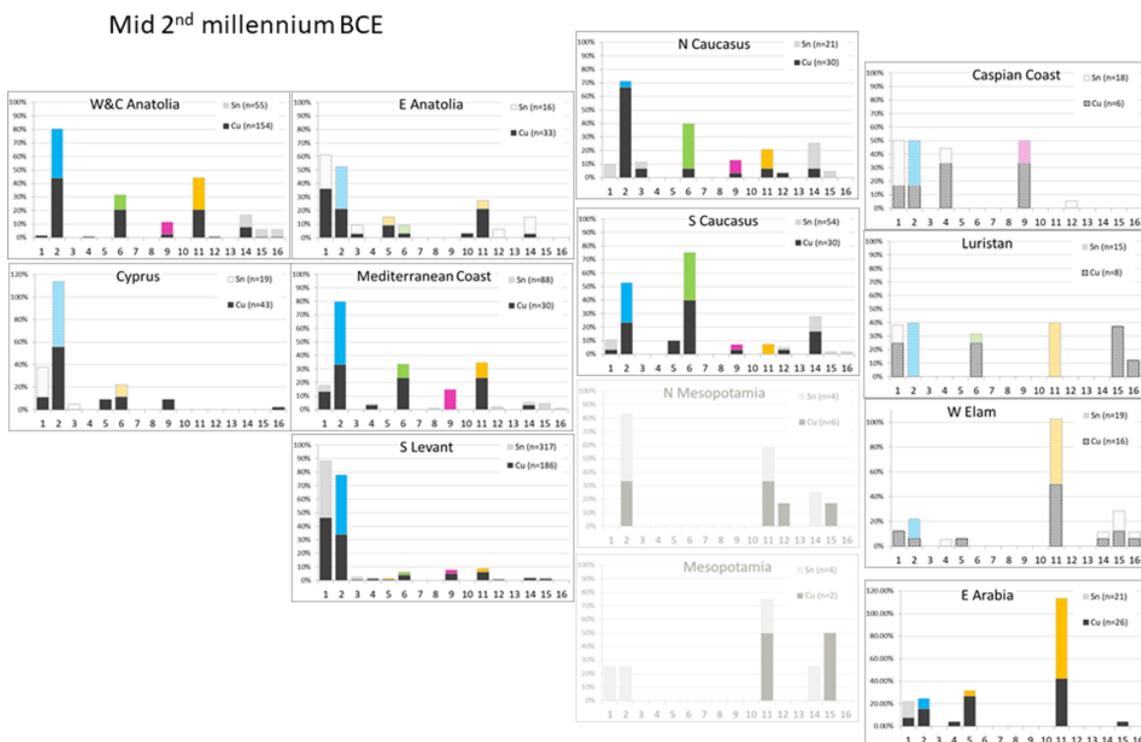


Figure 133: mid 2nd millennium BCE 'data map' of Southwest Asia presenting the ubiquity of copper groups in untinned copper and tin-bronze regional assemblages

Clean	As	Sb	Ag	Ni	AsSb	SbAg	AgNi	AsAg	SbNi	AsNi	AsSbAg	SbAgNi	AsSbNi	AsAgNi	AsSbAgNi
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

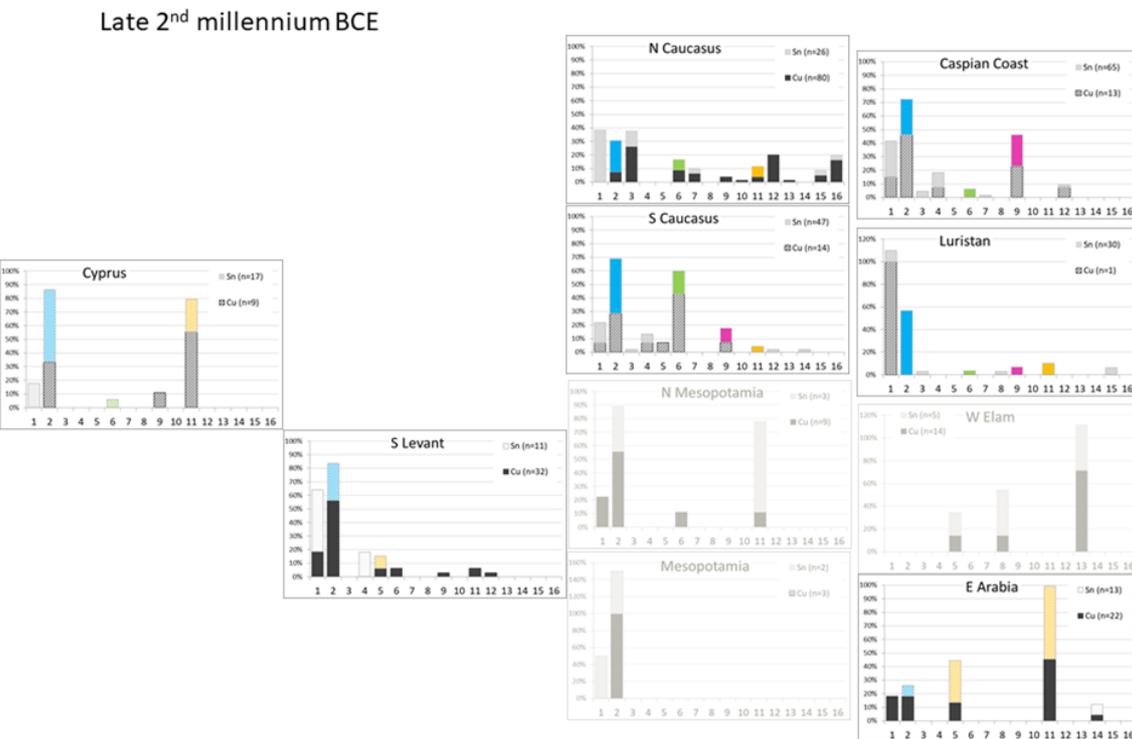


Figure 134: late 2nd millennium BCE 'data map' of Southwest Asia presenting the ubiquity of copper groups in untinned copper and tin-bronze regional assemblages

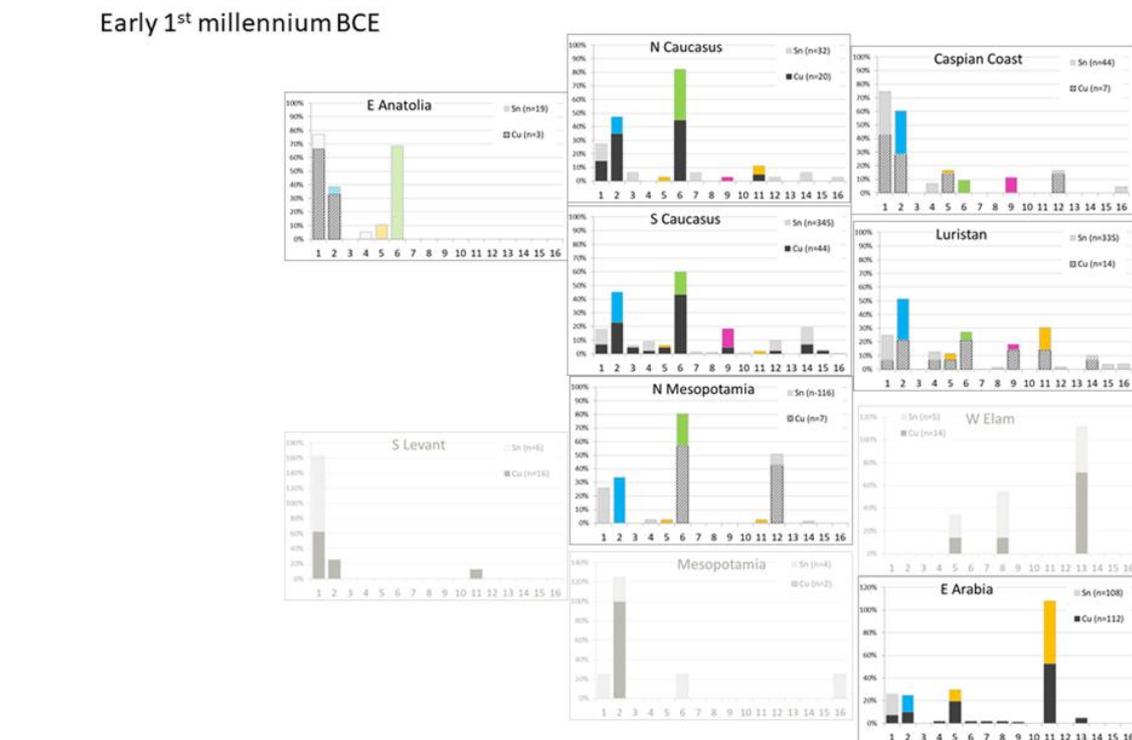


Figure 135: early 1st millennium BCE 'data map' of Southwest Asia presenting the ubiquity of copper groups in untinned copper and tin-bronze regional assemblages

As is to be expected from previous discussion about the Persian Gulf trade AsNi copper is most prevalent in the south-easterly regions of Southwest Asia but is also present to a slightly lesser degree in more northerly regions. This group becomes less ubiquitous from the early to mid- 2nd millennium BCE, when that trade was interrupted, though there is still a strong signal of AsNi copper in Eastern Arabia. This copper group also remains active in West and Central Anatolia, though this may indicate the continued exploitation of copper ores found in the Eastern Anatolian and Caucasus highlands, as in the Late 4th millennium BCE (Chernykh 2017b). Where AsNi copper is ubiquitous across Southwest Asia and throughout time, it is visible both in the tin-bronze assemblages *and* the untinned copper assemblages – this would indicate that both copper and tin are being traded simultaneously, but unfortunately cannot tell us if the tin-bronzes were also traded pre-alloyed.

There is a clear northern grouping of AsSb copper (copper group 6), as visible in section 1.1 of this chapter, and again it is frequently associated with both tin-bronze and untinned copper. It is interesting to note that it is rarely as common in the copper compositions of Mesopotamia, Western Elam, and Eastern Arabia, either as tin-bronze or untinned copper. It would seem that this copper type was traded as copper, however, and later mixed with tin since it is more ubiquitous in untinned copper assemblages than tin-bronze, except for when it is in use in the Northern Caucasus. There is appears slightly more often in tin-bronze which could be an indication of tin-bronze traded from the southern Caucasus pre-alloyed.

AsAg copper (copper group 9) is usually confined to the northeastern regions of Southwest Asia, appearing in the Southern Caucasus, Luristan, and the Caspian Coast most frequently throughout time. However when tin-bronze is made of this copper group it frequently occurs *without* its simultaneous presence in the untinned copper assemblages, though the group is not at all common. As the group is most often found unalloyed to tin in Luristan, it is possible that it represents material originating from that region. The instances of tin-bronze in other regions made of this AsAg copper may therefore indicate the sporadic trade of pre-alloyed tin-bronze.

3 Tin distributions within copper groups

3.1 Copper group 11 tin-bronze tin distributions in the late 3rd millennium BCE

Continuing with our focus on the Persian Gulf trade and the attempt to ascertain how tin may have been traded along this route, late 3rd millennium BE AsNi (copper group 11) tin-bronze assemblages and their tin-bronze distributions are compared with the contemporary regional tin-bronze assemblages that are not made of that copper composition. If we compare Figure 136(a) with Figure 137(a) we can see that the tin-distributions of AsNi tin-bronzes from Eastern Arabia and Mesopotamia are strikingly different: where the Mesopotamian assemblage has a more traditional distribution of tin which peaks at ~11.5% Sn, the Eastern Arabian assemblage has an apparently sporadic approach to the addition of tin to copper. This approach is mirrored in the remaining tin-bronze assemblage (Figure

136(b)), though it is worth mentioning that there is a gap in tin content between 11.5% and 20.5% that is filled in the AsNi tin-bronze assemblage, and fewer objects contain low tin contents in the latter. Could this indicate a more traditional approach to the addition of tin to 'local' copper?

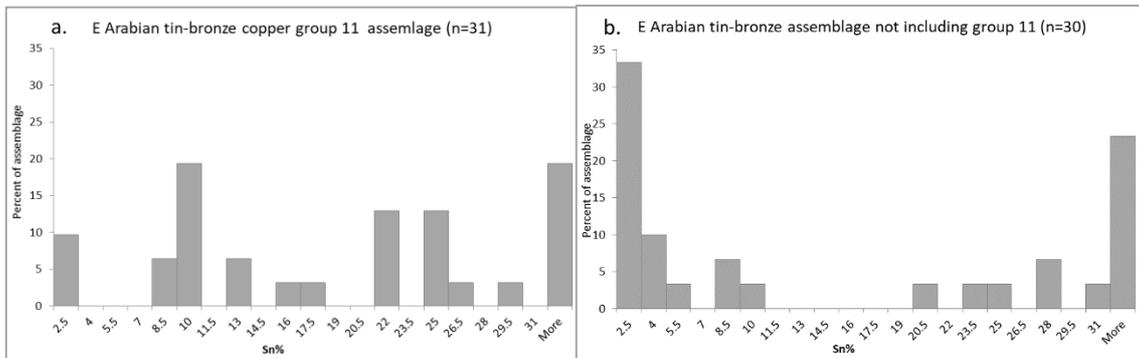


Figure 136: late 3rd millennium BCE Eastern Arabian tin distributions of tin-bronzes from (a) AsNi copper and (b) the remaining copper compositions in the tin-bronze assemblage

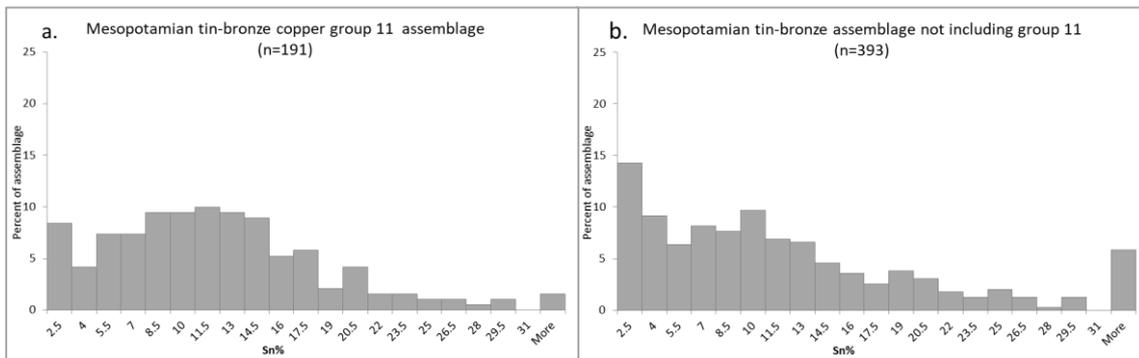


Figure 137: late 3rd millennium BCE Mesopotamian tin distributions of tin-bronzes from (a) AsNi copper and (b) the remaining copper compositions in the tin-bronze assemblage

The tin distribution in the Mesopotamian AsNi tin-bronze assemblage has an emphasis on tin present at between 8.5% and 14.5% Sn, which is not mirrored in the Eastern Arabian assemblage. This could be an indication that tin was not transported pre-alloyed from Eastern Arabia to Mesopotamia, or we might expect to see a similar tin distribution. What we do see in Mesopotamia, on the other hand, are a collection of very high tin bronzes in both AsNi copper and the

remaining copper groups. This is also apparent in Eastern Arabia: these high tin compositions (reaching 70% in some objects) are considered extraordinary and a product of tin-enrichment produced by post-depositional corrosion but they are rarely mentioned in the case of Mesopotamia (Weeks 2003; Cuénod 2013). As such quantities of tin are rarely seen outside these two regions and the process of corrosion occurs in objects across Southwest Asia, it could instead be seen as an indication that some tin was transported pre-alloyed. Is it possible that very high tin was pre-fabricated as a format for trade? Further and concerted study of these high tin objects and their typology would be necessary to involve more than supposition however.

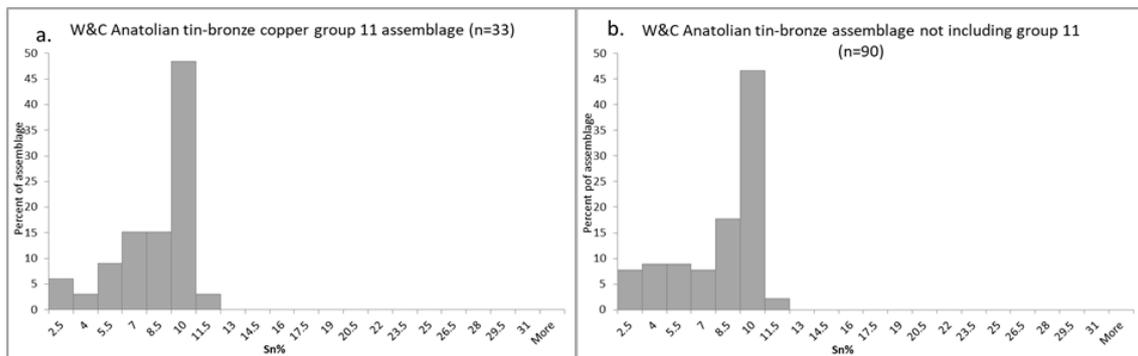


Figure 138: late 3rd millennium BCE West and Central Anatolian tin distributions of tin-bronzes from (a) AsNi copper and (b) the remaining copper compositions in the tin-bronze assemblage

From Figure 138 (a and b) we see a different picture once again: the tin-bronze assemblage of West and Central Anatolia shows an extremely similar tin-distribution when formed of AsNi copper as when it is formed of other copper groups. It also indicates a tight tradition of 10% Sn as the optimal quantity. The similarity across copper types indicates that tin was imported to West and Central Anatolia as a separate material and added to the copper in use at the time.

Looking at these three regions by AsNi copper and their differing approaches to the quantity of tin within the assemblages seems to indicate that tin was not traded pre-alloyed in the main and highlights that tin-bronze was produced according to disparate regional tradition. However looking back at Figure 131 importation of metallic tin or tin ore may not have been the model applied to all regions: the Southern Caucasus, Mediterranean Coast, and Luristan tin-bronze assemblages are sometimes represented by copper groups not present in the untinned assemblages. Unfortunately the most frequently occurring copper groups unmatched in the untinned copper assemblages (groups 14, 15, and 16), are not present in sufficient numbers for a reliable focus on tin distributions.

3.2 Copper group 6 tin-bronze tin distributions in the early 1st millennium BCE

In Cuénod (2013) it was concluded both that Luristan was producing large quantities of tin-bronze from the late 2nd onwards, and that the regional tradition was relying on local sources such as the Deh Hosein mine and possibly others. It was also suggested that tin may have arrived via the Caucasus, though as the database did not include data from the Caucasus this could not be tested. In this section the movement of tin-bronze between Luristan and the Southern Caucasus will be investigated through the tin distribution of tin-bronzes made of AsSb (copper group 6) which, as noted in section 2.3 of this chapter appears to be closely associated with the Caucasus mountains.

Figure 139(a) and Figure 140(a) show the tin distribution of the AsSb tin-bronze assemblages from Luristan and the Southern Caucasus. Not only are these two regional assemblages very similar, possibly also indicating recycling or re-use by the double peak of tin content, they are visibly different from their contemporary tin-bronze assemblages made from other copper compositions. This indicates that this material was treated separately in some way and that there may have been a connection between the two regions. What is also striking, however, is the heavier reliance on lower tin-bronze in the Caucasus in both assemblages.

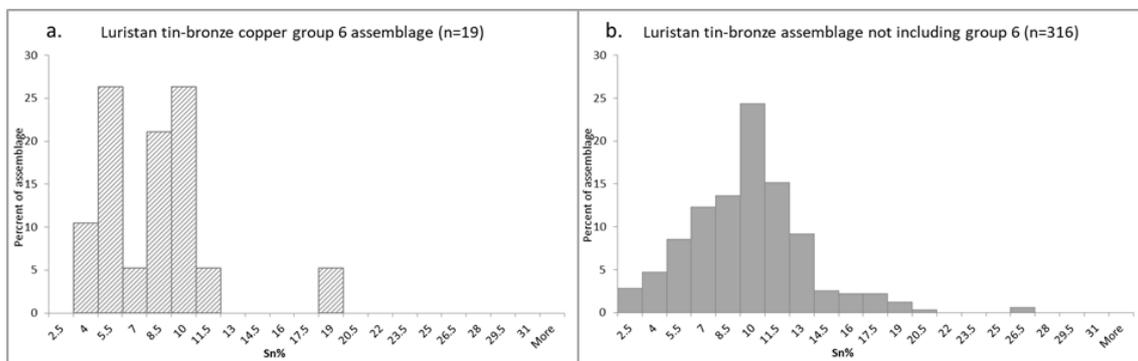


Figure 139: early 1st millennium BCE Luristan tin distributions of tin-bronzes from (a) AsSb copper and (b) the remaining copper compositions in the tin-bronze assemblage

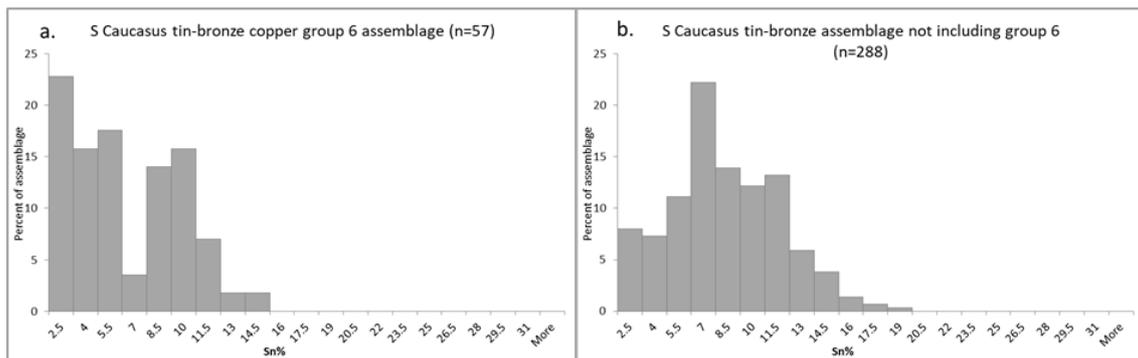


Figure 140: early 1st millennium BCE Southern Caucasus tin distributions of tin-bronzes from (a) AsSb copper and (b) the remaining copper compositions in the tin-bronze assemblage

As mentioned in Cuénod (2013), the tin-distribution in Luristan tin-bronzes represents that of a primary production region. The stark difference in the tin distribution of AsSb tin-bronzes from the rest of the assemblage made of the

remaining copper groups certainly marks them out as part of a separate tradition, and their evident similarity with the AsSb tin-bronze assemblage from the Southern Caucasus does indicate some sort of possible link. However the Southern Caucasus assemblages do not represent those of a primary production centre, which should theoretically have a single peak of tin content as in Figure 139(b). This could have more to do with the organisation of copper-base production in the Caucasus at this time, which was disparate and localised in small but ubiquitous production centres (Erb-Satullo *et al.* 2017; Erb-Satullo *et al.* 2014).

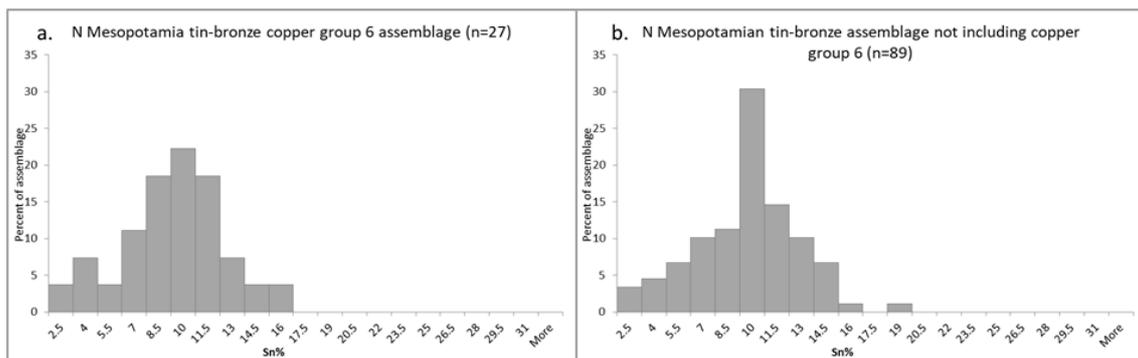


Figure 141: early 1st millennium BCE Northern Mesopotamian tin distributions of tin-bronzes from (a) AsSb copper and (b) the remaining copper compositions in the tin-bronze assemblage

If the tin distributions of the Luristan and Southern Caucasus tin-bronze assemblages are compared with the contemporaneous tin distributions from Northern Mesopotamia, however, a more traditional primary production signal is indicated further south. This is interesting as AsSb is not as frequently found in Northern Mesopotamia as in the Southern Caucasus (Figure 130 to Figure 135). Northern Mesopotamia was the homeland of the Assyrian Empire from the first millennium BCE and often sought to expand its territories, especially into metal rich areas (Barnett 1982, p.327; Van de Mierop 2016, p.217; Akcil 2006, p.91).

This pattern may reflect Assyrian control of copper deposits located in the Caucasus, or possibly the tribute that was known to have been sent to Assyria at the time. Assyria evidently also had access to sufficient quantities of tin which in turn precluded the need or tradition of recycling of recycling tin-bronze objects, as there are far fewer low tin bronzes in the assemblage. Unfortunately there are not sufficient numbers of untinned copper with which to compare the copper group ubiquity of tin-bronze and 'local' copper to draw any conclusions about how tin was imported to the region. Such a tin distribution, however, does suggest strict adherence to a specific ratio of tin to copper as 30% of all tin-bronze objects contain ~10% Sn.

4 Chapter Summary

The Oxford System for trace elements is a useful diagnostic tool with which to pull out other aspects of metallurgical tradition, and from there to have a better understanding of regional metallurgical traditions. Through the recognition of AsNi, As-only, and AsSb as recurrent and regionally ubiquitous copper groups it has been possible to investigate further information about regional approaches to tin-bronze production. Owing to the vast nature of the area however and the many factors that influence flow of copper, it is not possible to understand a Southwest Asian-wide acquisition of tin. This is also possibly due to the region itself and a lack of any one organised pan-regional tin trade. Meanwhile it has enabled conclusions to be drawn about certain regional access to tin and the possible routes through

which it arrived, as well as the regions it was subsequently traded to. Although a useful tool to compare regional traditions, this method can only help us work out questions of *how* certain technological aims were achieved but not *why* they were attempted or how the results were *perceived* by users, which will now be addressed in Chapter Seven.

Chapter Seven: Perception of metals

This chapter is concerned with the interaction of people, both ancient craftspeople and modern archaeologists, with copper-alloys by focussing on colour. Colour can act as both a signifier of certain behavioural properties and the desired outcome in and of itself, but it is a subjective topic that is hard even for linguists, philosophers and psychologists of the modern day to pin down. In the following paragraphs first the difficulties of studying colour in metallurgy are outlined, before moving on to a summary of recent research which aims to redress these obstacles. The recent methodology of *Perceptive Categories* introduced by Kuijpers (2017) is then described and four case studies from the Southwest Asian database are presented and fitted into this framework. The aim is to contribute to the discussion of how colour can be utilised to indicate technological and cultural choices made by ancient people in the production and use of copper-alloys and provide further evidence to define the parameters of these categories.

1 The importance and problems of colour

Though the importance of colour in ancient societies is well accepted in terms of ceramics, masonry, precious stones, and glass (e.g. the cultural significance of the colour blue in Mesopotamia (Sagona 2017, p.413), the colour significance of metals is less often discussed. In part, this is due to an absence of easily definable colour categories which can be measured against one another based solely on the presence of a particular trace element, as in glass where the presence of cobalt renders the glass as Egyptian blue – a visually distinct colour from the turquoise blue glass created by the presence of copper. There are also fewer visible cues on the material's surface or structure which affect the reflection of light and therefore the appearance of colouration; glass can be opaque, translucent, rough or polished smooth but copper and its alloys can only be opaque and metallic, whether tarnished or polished.

Rather than distinctive colour categories which depend on the presence of *colour-specific elements* as in glass colourants, where the compositional quantity of the element only affects the saturation, in copper-alloys we actually see a continuous incremental scale of metallic colour ranging from copper red to silvery white, with the hue lightening the more the alloying element is added, regardless of what that alloying element actually is: the metallic colour is therefore dependant on the *compositional quantity of various alloying-elements*, each of which produce a similar colour effect in the metal, though with an element-specific tint (e.g. the purplish silver of copper containing 25% Sb). Though the resultant colour of the copper-alloy was no doubt sought and achieved by varying the quantity of these added materials, it is much harder to retrospectively impose a culturally

meaningful and determined set of colour categories onto this continuous scale of differently coloured metal objects, and to understand to what extent they were aimed for by the producers.

2 Current colour-focussed research

After several decades when the main focus of studies into technological choice was to test the mechanical and behavioural qualities of copper and its alloys, based on the assumption of the superiority of tin-bronze over other copper-alloys (Lechtman 1996), colour is now a prime focus. The aim of this type of research is clear; even though behavioural and mechanical qualities of copper-alloys can be presumed to have been paramount in the technological choices of ancient craftspeople, so too can colour be presumed. The colour of the produced artefacts would also have had an impact on (and been impacted by) the cultural beliefs and fashions of consumers. Attempting to discern patterns in colour-specific copper-alloys therefore brings the individuals who interacted with copper into a sharper focus.

A concurrent strand of research has also been a wider reflection on the cumulative effect of several alloying elements, both on colour and mechanical properties (Radivojević *et al.* 2018; Mödlinger and Sabatini 2017; Mödlinger *et al.* 2017). Radivojević *et al.* (2018) have begun experimental work on the varying colours of copper-arsenic-tin tertiary alloys by producing sixty-four variants of copper-arsenic-tin, which have then been chemically analysed, photographed, and

presented on a ternary diagram. Objects containing these elements can then also be plotted against this diagram, potentially giving an indication of the original colour of the object.

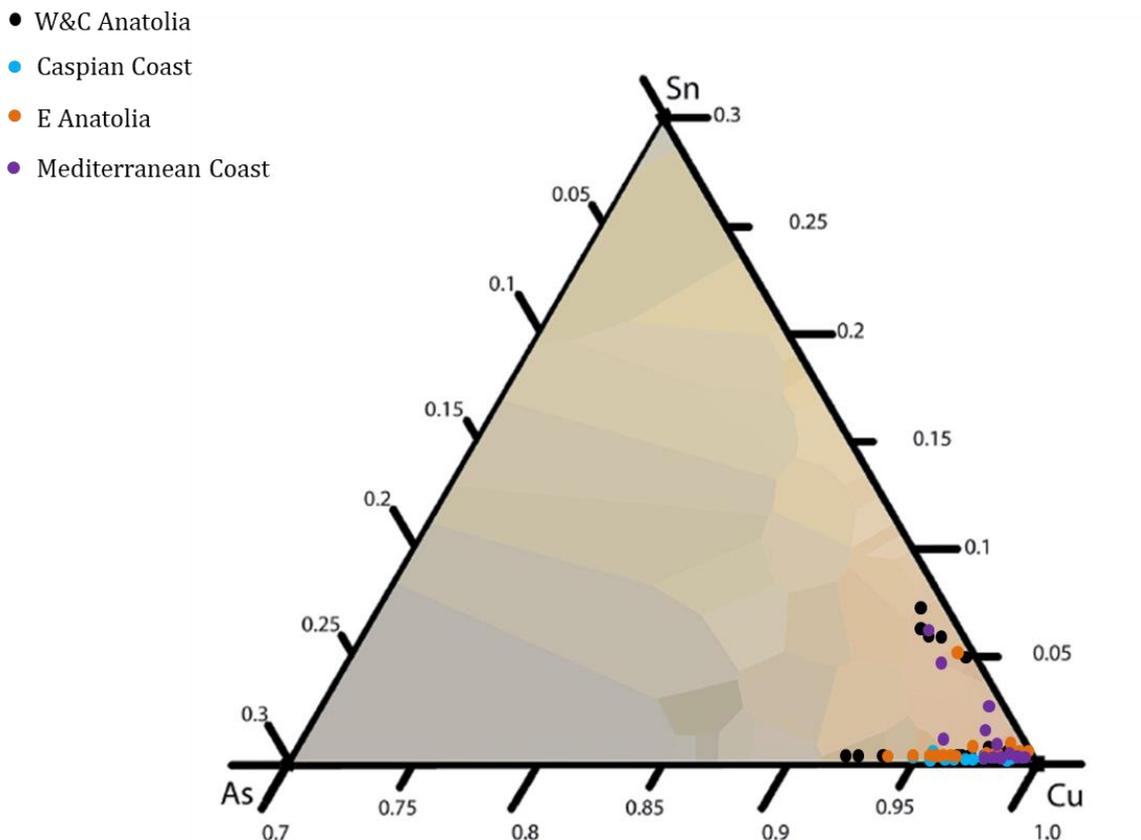


Figure 142: Late 4th millennium BCE copper-base assemblages from W&C Anatolia, the Caspian Coast, E Anatolia, and the Mediterranean Coast plotted onto ternary diagram depicting the colour of alloys dependent on the quantity of arsenic, tin and copper in the chemical composition (ternary diagram created by Radivojević *et al.* 2018, p.115). Reprinted from *Journal of Archaeological Science*, Vol 90, M. Radivojević *et al.*, Experimental design of the Cu-As-Sn ternary colour diagram, 106-119., Copyright (2018), with permission from Elsevier.

Figure 142 depicts the late 4th millennium BCE copper-alloy assemblages from West and Central Anatolia, the Caspian Coast, Eastern Anatolia, and the Mediterranean Coast by arsenic-tin-copper compositions, highlighting the differences in colour. We can see that a small group of tin-bronzes containing 5 – 10% Sn were a distinct colour from the unalloyed copper objects, but a group of low tin bronzes from the Mediterranean Coast may not have been sufficiently visibly distinctive from pure copper to recognise as a separate material. In fact, the

difference in the colour of all these copper-base objects may only be visible when able to be directly compared to an object of a different composition.

Mödlinger *et al.* (2017) have conducted similar research on binary alloys, charting the effect of arsenic, nickel, antimony, and tin on copper colour with a spectrophotometer. However, they state that this quantification of colour is not sufficient – perception of colour relies on too many extra factors and does not inform us how the objects or material were perceived by their makers and users (*ibid.* p.21).

3 Perceptive Categories

This then led to Kuijpers' *Perceptive Categories* (2017), which combine both colour and behavioural attributes of certain alloys with metallographic data and craft knowledge of historical and contemporary craftspeople. The *perceptive categories* are displayed in Figure 143 describing the colour and general behavioural qualities of the copper.

One obstacle in the use of these categories with Southwest Asian data is that they were originally developed using metallographic evidence of manufacturing techniques on a single object type (axes) from Central Europe, rather than all object types across the vast region of Southwest Asia – the categories may therefore not be completely transferable across data types. This study has had to rely on the assumption that the behaviour of copper, as dictated by alloying elements, is universal.



Figure 143: Colour and behavioural qualities of copper-alloys by Perceptive Category (Kuijpers 2017, p.13). This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>)

The lack in Central Europe of copper ores rich in arsenic, antimony, nickel, or silver has also dictated that these four alloying elements have been allocated to the same category, though the effect of each element on the copper alloy differs slightly (NB: as mentioned above the main known difference is an added tint to the finished metal). It is also very common to find objects in Southwest Asia containing two or more of these 'corrupting elements': although it is unknown what affect a combination of those elements may have on the qualities of the resulting metal. Nor is it known whether the element present in the highest quantity has a proportionately more significant affect than the lower alloying elements. As research on the cumulative effect of alloying elements is yet to be conducted, in this thesis the corrupting element present in the highest quantity has been taken to determine its perceptive category. Due to their common occurrence in Southwest Asia further work is clearly necessary on the combined effects of alloying elements.

As in Kuijpers (2017), where objects have quantities of both corrupting elements and tin, these have been labelled 'Indet' and largely left out of the following discussion. Unlike Kuijpers, however, if corrupting elements and tin are present, but one is below the threshold of type I – the category in which the alloying element is considered imperceptible even to a skilled worker – then the copper is assigned to the category type of the remaining alloying element (e.g. if containing 4% As, then it would be designated category type II, despite the presence of 2% Sn). This is based on the assumption that if the higher alloying element was added purposefully, it was added to copper that was indistinguishable from unalloyed

copper and therefore the technological choice was to increase or enhance the properties based on the element present in a higher quantity.

3.1 Changing colours over time

In order to avoid repetition of discussion in the previous chapters four case studies of this method are outlined and discussed below, rather than providing an entire overview of regional copper use by *perceptive category* from the 4th to 1st millennium BCE. Before these examples are presented, however, two maps follow to indicate the overall change in copper colour from the beginning of widespread tin-bronze use to the beginning of the 1st millennium BCE.

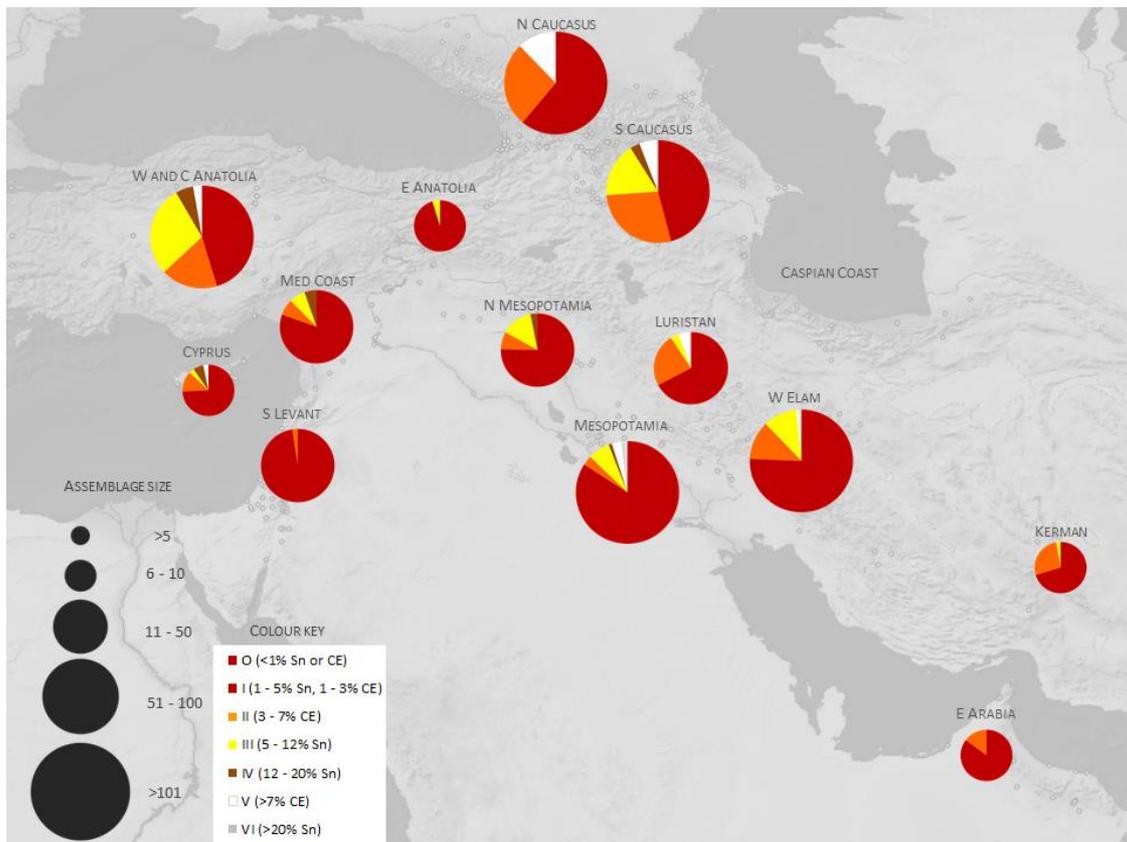


Figure 144: mid-3rd millennium BCE assemblages categorised by perceptive categories (CE in key is short for 'corrupting elements' - As, Sb, Ag and Ni)

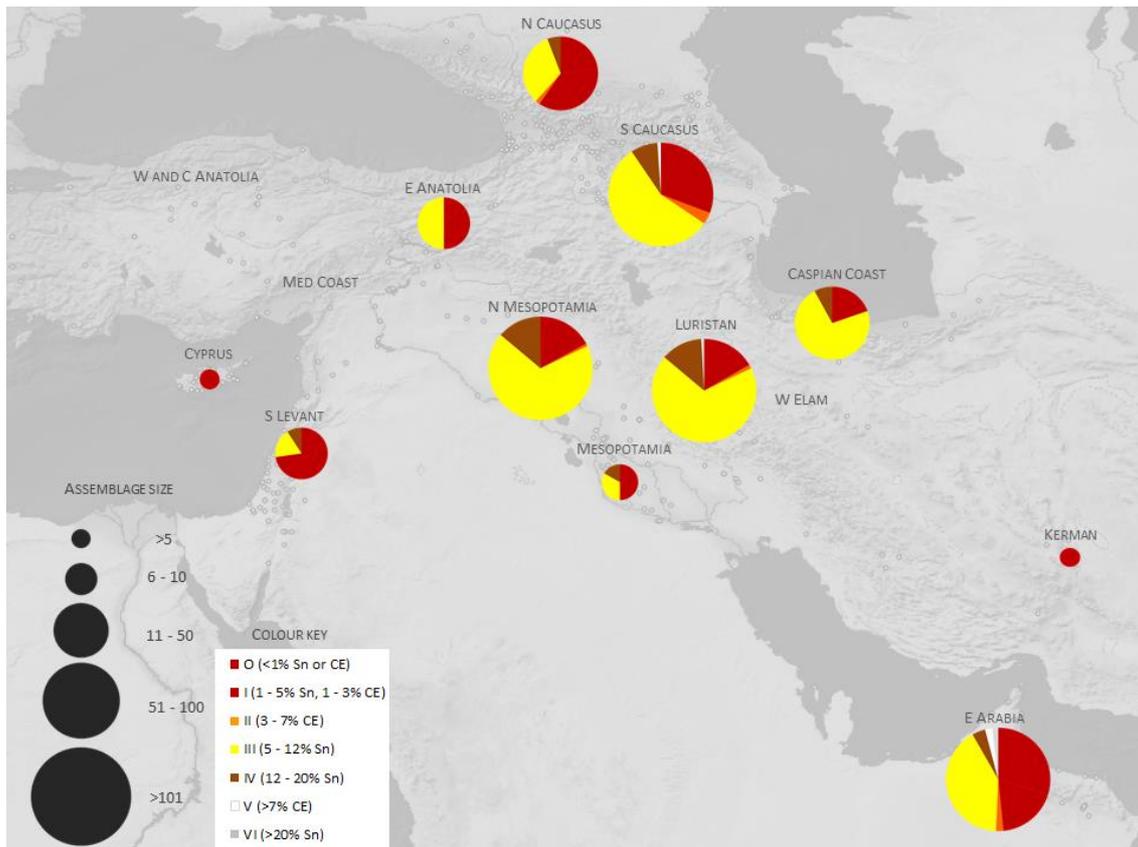


Figure 145: early 1st millennium BCE assemblages categorised by perceptive categories. (CE in key is short for 'corrupting elements' - As, Sb, Ag and Ni)

As can be seen from those representations of copper use by its appearance, after a mid-3rd millennium BCE emphasis on red-copper (Figure 144), by the early 1st millennium BCE the copper in use is predominantly yellow and orange (Figure 145). This change is ostensibly due to the rise in tin content and number of objects containing higher tin levels, but did this move towards yellow tin-bronze (and its accompanying behavioural qualities) occur due to a decision based on aesthetics, properties, and value or was it a coincidence based on better access to material? The very fact that the two high-tin and high-corrupting-element categories (V and VI) do not become the most dominant colour groups, suggests that the aim was not simply to increase the amount of alloying element as much as possible, which appears to have been the objective in early 4th millennium Southern Levant high-

status metallurgical display. The stabilisation of alloying-element quantities under the highest alloying groups indicates a technological choice not to value the aesthetic properties over the behavioural qualities.

By the 1st millennium BCE gold was very popular and this appeal of gold could have influenced fashion, or the appeal of both yellow-copper and gold could reflect a cultural significance placed on the colour itself. By the early 1st millennium BCE, we also witness the altered metallurgical tradition of producing common implements, tools, and weapons from iron rather than copper, indicating the reservation of tin-bronze for high-status and decorative objects.

We can also use these *perceptive category* patterns to look for broad trends between regional or pan-regional traditions. In the mid-3rd millennium BCE (Figure 144) there is little technological cohesion across Southwest Asia, despite the predominant use of red-copper. Regional metallurgy was therefore potentially disparate and dependant on different minerals or different quantities of certain minerals at this point. Though it seems (as discussed in Chapter Six) tin was traded independently from copper, different regions appear to have received larger or smaller shipments of tin and made use of it according to their regional preferences. For example, Mesopotamia has more objects containing >20% Sn, and fewer containing 5 – 12% Sn: indicating an emphasis on visibly high-status objects. Northern Mesopotamia and West and Central Anatolia seem to have placed more emphasis on the number of tin-bronze objects, which were visibly different from normal copper, but not extravagantly so. Cypriot smiths on the other hand, despite the more limited access to tin owing to the isolation of the island in the mid-3rd millennium BCE, appear to have opted most for the gold-coloured tin-bronzes (12

- 20% Sn), possibly owing to the popularity of gold on the island. The Mediterranean Coastal assemblage provided equal numbers of type II, III, and IV copper, perhaps owing to the region's position along trade routes.

In the early 1st millennium BCE (Figure 145) the pattern of copper-colour use is much more uniform across Northern Mesopotamia, Luristan, the Caspian Sea Coastal region, and the Southern Caucasus indicating cohesion between them. The regions around the (physical) periphery, especially towards the west of the region, show differing and disconnected traditions. The picture provided by this map is not one of disruption across Southwest Asia owing to the collapse of the Bronze Age, but of an emergent, flourishing, and drastically different Iron Age metallurgical tradition in the east of the region, with a simultaneous absence of trade and tin-use in the eastern Mediterranean region. Eastern Arabia and the Northern Caucasus indicate flourishing copper-base traditions, which are largely separate from the uniform shared traditions of the west-central region.

4 Perceptive categories and Southwest Asian case studies

The four case studies that follow cover several different time periods, regions, and object categories in order to get a broad picture and to look more closely at certain aspects of technological choice. The first presented are axe types in the mid-3rd millennium BCE, split into regions and presented as a scatter plot of tin and arsenic (nickel, antimony and silver are not common enough to present a regional comparison, though further study into these additional elements would of course

be interesting). The second and third studies are quite similar both in region (Cyprus and Southern Levant respectively) and in object type: early 2nd millennium Cypriot weapons vs ornaments and accessories, and late 2nd millennium Southern Levant axes vs pins. The final study presents early 1st millennium Assyrian musical instruments.

4.1 Mid-3rd millennium BCE axe-types

Figure 146 to Figure 148 present three differing typological categories of axes that can be found across several regions of Southwest Asia in the mid-3rd millennium BCE. Flat axes and Crescent axes are similarly made up of the various perceptive categories, with the largest category of metal type being Type I (with unnoticeable levels of either tin or arsenic).

The largest numbers of Flat axes are from West and Central Anatolia, none of which contain 'perceptible' levels of arsenic, but all vary in tin content. The axes containing tin do not visibly adhere to the perceptive categories, though there are small groupings – one group of five objects containing 7% – 9% Sn, and two objects containing ~13% Sn. The Southern Caucasus Flat axes are also dotted randomly within and amongst the West and Central Anatolian axes, this could suggest a similarity of mineral access, or traditions linked across the Black Sea, though as pointed out in Chapters Three and Five, the mid-3rd millennium BCE South Caucasus assemblage contains a large number of insecurely dated objects.

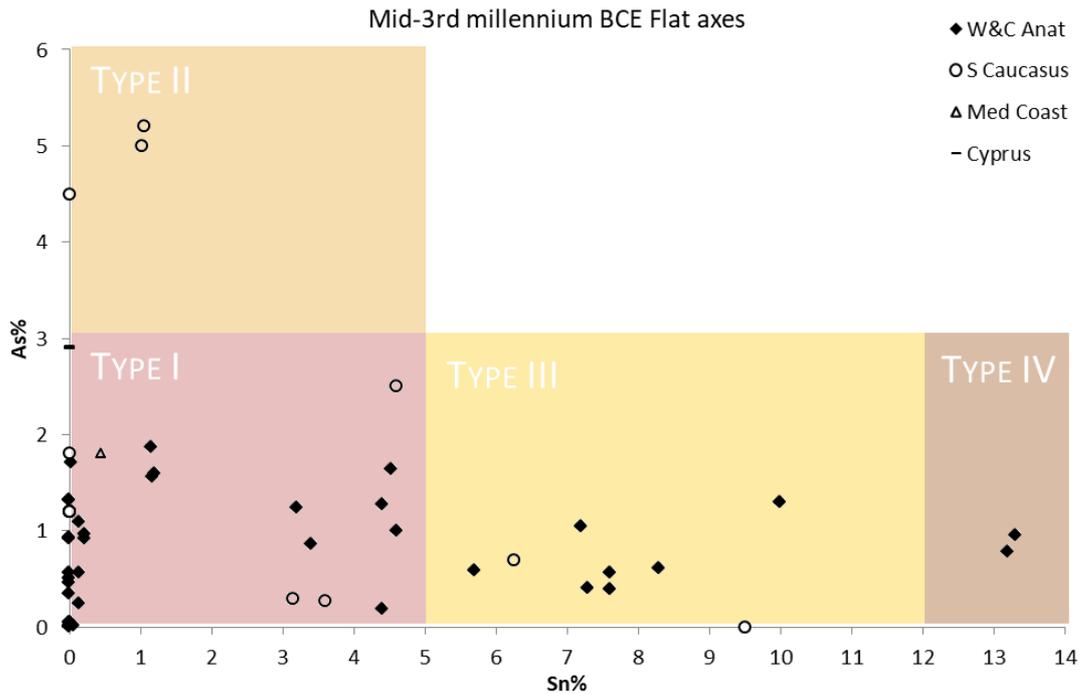


Figure 146: mid-3rd millennium BCE flat axes separated by region and overlaid with perceptive categories, charted by arsenic content vs tin content

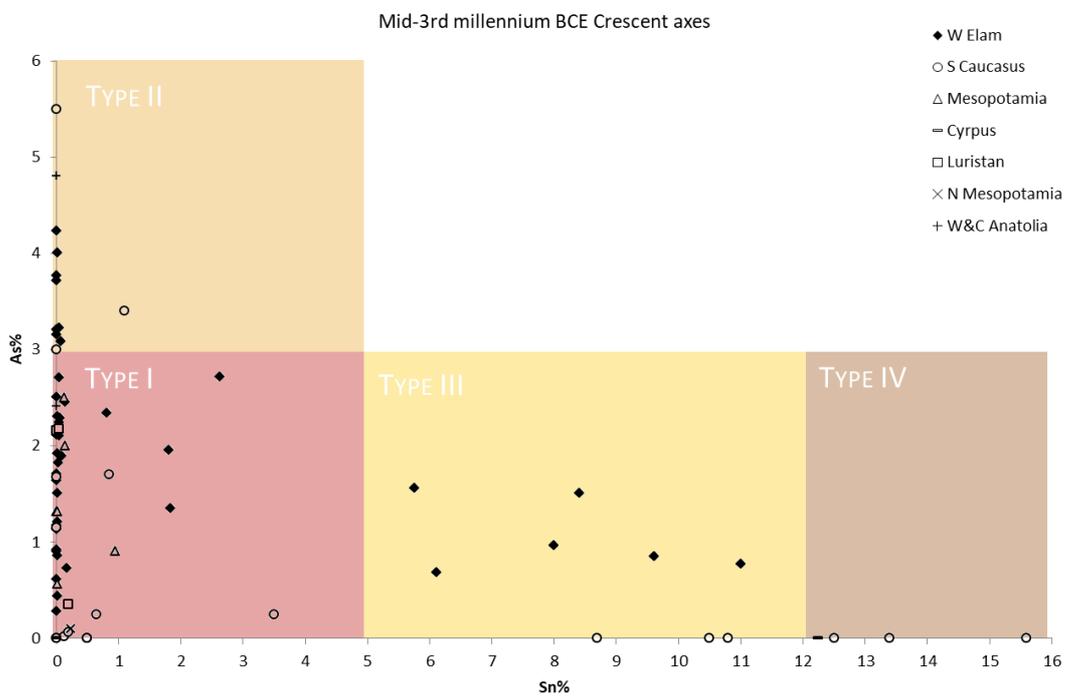


Figure 147: mid-3rd millennium BCE crescent axes separated by region and overlaid with perceptive categories, charted by arsenic content vs tin content

In Western Elam Crescent axes (Figure 147) are either made of type I (<5% Sn, <3% As, Sb, Ag, or Ni), type II (3% – 7 % AS), or type III (5% – 12% Sn). It is interesting to note that the axes made of type II contain no tin at all, whereas all Western Elam type III copper Crescent axes contain between 0.5% to 1.5% arsenic, suggesting that in the manufacture of tin-bronze Crescent axes tin was added to an already arsenic-rich copper. The Southern Caucasus provided many examples of both Flat and Crescent axes, but it is interesting to note that the Crescent axes in this region contain higher quantities of tin, which does not occur in the Flat axes. In fact Flat axes from the Southern Caucasus display a prominence of high-arsenic contents.

Though there are visibly defined groups of each axe type within the *perceptive categories*, splitting the objects by typology in this case does not indicate a different approach to the manufacture of Crescent or Flat axes, nor a very strict adherence to the category ranges. The main difference between the axe-types is that Flat axes are more likely to have varied tin contents, suggesting a lack of concern or control over the precise alloy combination. This is less visible in the Crescent axes, which are more controlled by perceptive category. However, it must be remembered that the data we have for the two axe-types also differs by region, so the patterns visible could be differences in regional tradition rather than typological traditions.

A different picture emerges all together when attention shifts to shaft-hole axes (Figure 148). No shaft-hole axes contain tin, but there are two distinct groups between type I (unnoticeable alloying elements) and type II (3% – 7% As: producing an orange-copper). This reveals a distinct choice in material dictated by

colour and behavioural qualities, as a significant number of West and Central Anatolian Flat axes from the same time period are made from perceptively different alloys.



Figure 148: mid-3rd millennium BCE shaft-hole axes separated by region and overlaid with perceptive categories, charted by arsenic content vs tin content

West and Central Anatolian metalsmiths in the mid-3rd millennium BCE appear to have intentionally made some axe-types from different copper-alloy combinations– a further example is shown in Figure 149. Ridge-necked axes from Mahmatlar in the Black Sea Region of Anatolia contain a very specific alloying composition – 0 -1.5% arsenic, and a range between 8 to 10% tin, which sits firmly within the range of *perceptive category III*, and would have exhibited very similar behavioural qualities. As the objects were found at the same site, it is possible that

they were made in the same workshop, or to a standard set of settlement specifications

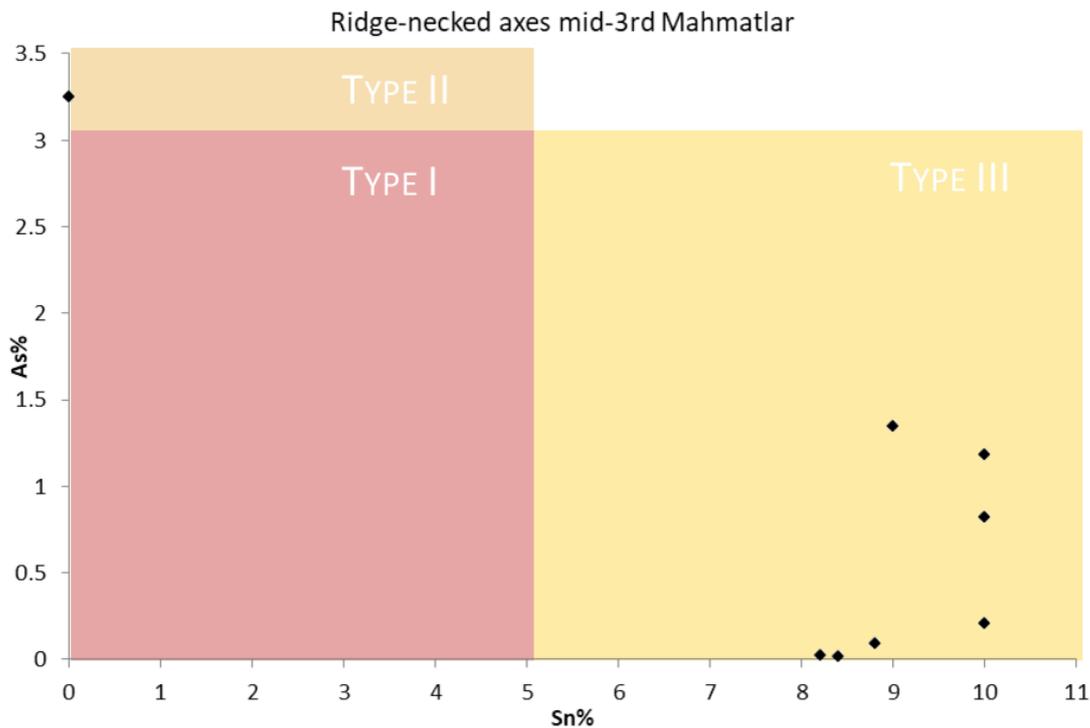


Figure 149: mid-3rd millennium BCE ridge-necked axes separated by region and overlaid with perceptive categories, charted by arsenic content vs tin content

These four axe typologies indicate grouping between *perceptive categories*, but without distinction by region, suggesting that regional traditions and access to material do not necessarily dictate the composition of an alloy, but an attempt to control colour, behavioural qualities, or both, during the manufacturing process. However the continued use of unalloyed (or unrecognisably alloyed) copper for use in all axe-types (except the specifically located ridge-necked axes), suggests a differentiation of status or quality of materials in use, perhaps dependant on the wealth of the buyer as in modern times. It is also possible that people valued different aspects of each material and had their own preferences and a range of colours and properties were produced across many object types. The ridge-necked

axes on the other hand represent an object where that choice did not exist for the consumer, and they appear to have been made to strict specifications, for which unalloyed copper was not suitable.

4.2 Early 2nd millennium BCE Cypriot ornaments and weapons

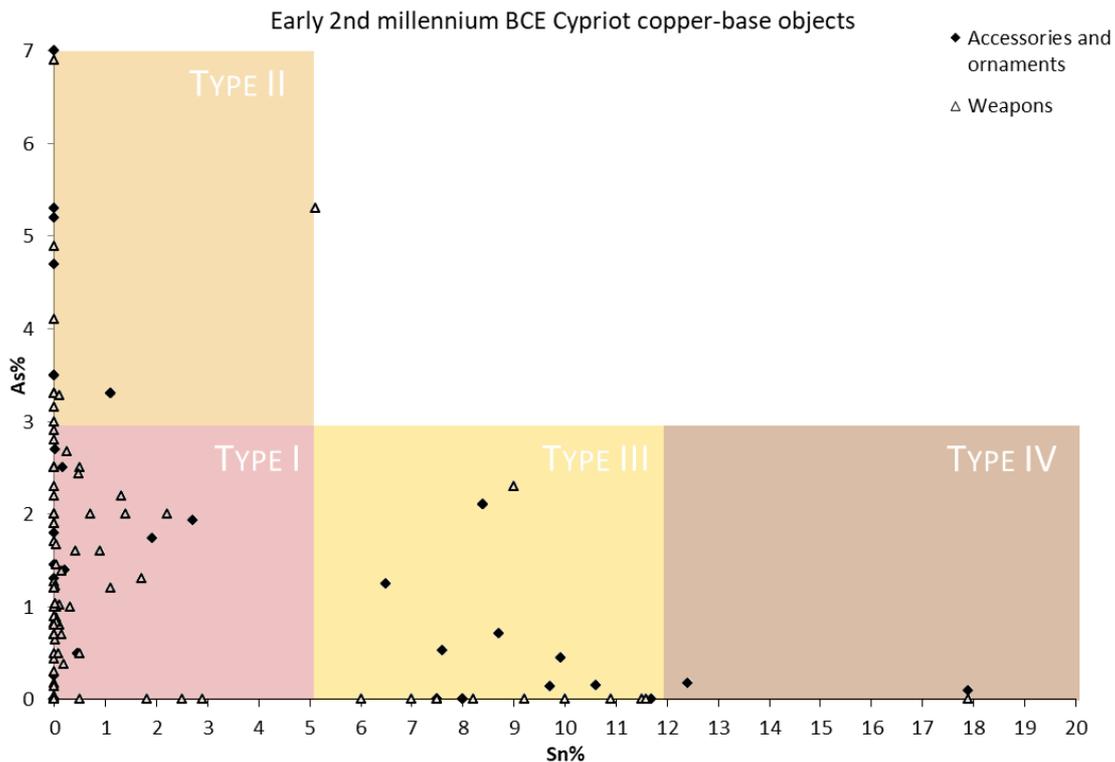


Figure 150: Early 2nd millennium BCE Cypriot copper-base accessories and axe assemblages overlaid by perceptive categories and charted by comparison of arsenic and tin

In early 2nd millennium BCE Cypriot copper-alloying traditions there are broad differences between category type (Figure 150). Accessories and ornaments (such as jewellery, statues and ceremonial equipment) are more likely to be grouped into perceptive category III (5% - 12% Sn) and contain between 0% - 2% arsenic. There is also a distinct group of weaponry (such as axes, daggers and spears), which belong to this category type, though they appear to contain no arsenic at all, in fact arsenic was not sought by the analyser. The majority of weapons belong to perceptive category type I (unnoticeably alloyed and unalloyed copper), with a

distinct grouping of up to 3% Sn and between 1 and 2.5% arsenic). It is odd to see a distinct group here as there would be perceptibly no difference in material – it is therefore possible that these represent recycled metal with a diluted tin content owing to the addition of unalloyed (or possibly arsenical-) copper. Both categories of objects are equally represented in type II (3% – 7% As), which is not surprising owing to the numerous arsenic-rich ores in the Troodos Mountains.

As might be expected on an island rich in arsenical-copper but devoid of tin, the *perceptive categories* of tin content are quite distinctly separate from one another. This could represent the importation of ready-made tin-bronze, or perhaps the careful separation of copper types when recycling – if craftspeople can recognise by colour when the tin content is becoming over diluted, they might choose to recycle those objects into smaller objects (such as pins) rather than add additional copper which would produce a depletion of colour and behavioural quality. This could also explain why there is a grouping of larger items within type I, containing some tin and some arsenic. It is possible that the type of use to which these weapons were put rendered the manufacture less important, or that the mixture of c.2% As and c.2% Sn creates another set of behaviours within the alloy which are as yet unknown.

The clear distinction between ornamental/display objects and weaponry based on colour indicates that in the early 2nd millennium BCE in Cyprus the appearance of copper objects was an important factor in manufacturing choice, and possibly the weapons within this category were also considered more for show than use.

4.3 *Mid 2nd millennium BCE Southern Levant pins vs axes*

If looking at axes and pins in the following period in the Southern Levant, however, the picture is almost the opposite (Figure 151). Though presenting a larger range of tin content, axes were more likely to be made of perceptive category type III (5% to 12% Sn), and pins more often made of type I. Pins either contain small quantities of tin or small quantities of arsenic, but not a mixture of both. As copper ore in the southern Levant rarely contains arsenic-bearing minerals, these could represent foreign imports. This distinction between pins and axes may indicate a higher ornamental value placed on axes. The northern reaches of the Southern Levant were continuously fought over by Egypt and the Hittites until the Battle of Qadesh in 1300BCE, which might explain why the largest typological category in the region during the mid-2nd millennium BCE is weaponry, and why type III (5 – 12% Sn) with improved casting qualities and durability may have been preferable for the fabrication of these objects rather than wasted on ornamental objects such as pins.

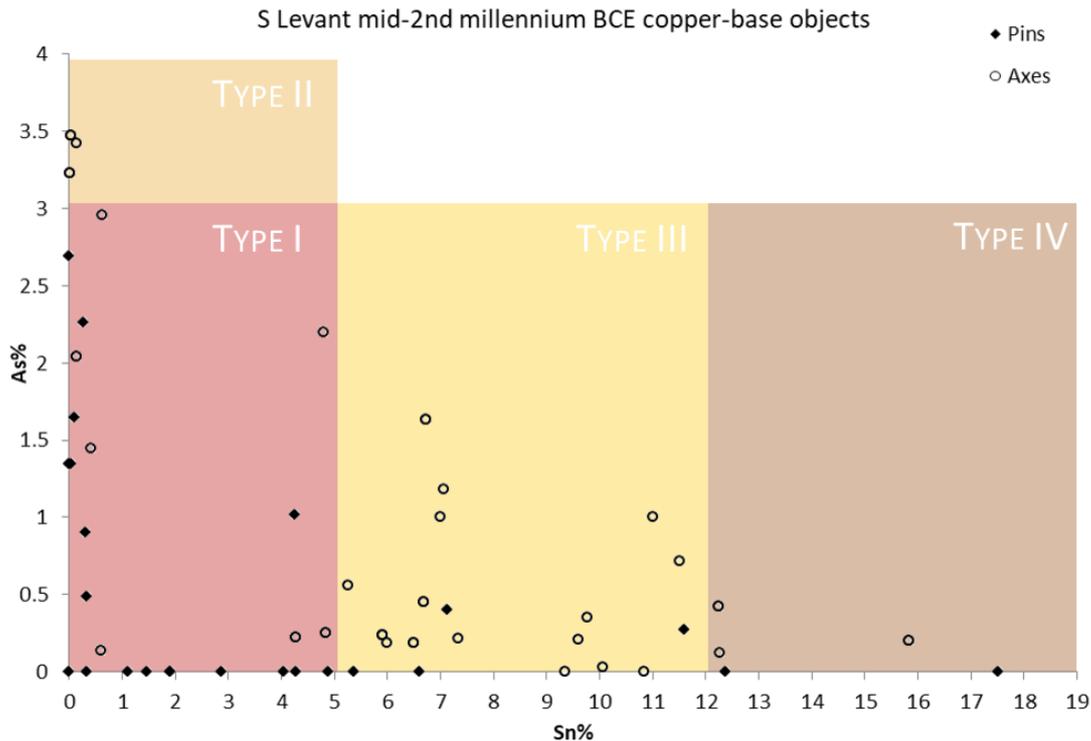


Figure 151: Mid-2nd millennium BCE Southern Levantine copper-base pin and axe assemblages overlaid by perceptive categories and charted by comparison of arsenic and tin

The lack of clear adhesion to the category could also imply a sense of haste during manufacture or could be an indication that type III ought to be split into two separate groups. Kuijpers (2017) refers to a possible break in type III at ~9% Sn, where the difference in behaviour and colour could be noticeable to craftspeople. There are two clear distinctions within type III; 4% – 7.5% Sn and 9 – 12.5% Sn, suggesting that this could be a possibility. If we look through the previous graphs, we do not see this pattern in early 2nd millennium BCE Cyprus (Figure 150) or Southwest Asian crescent axes (Figure 5), but the ridge-necked axes from Mahmatlar all contain between 8 – 10% Sn (Figure 7), and the flat axes from across Southwest Asia indicate a grouping between 5.5 and 8.5% Sn (Figure 4). Were these then typological differences, regional differences, or coincidental differences? Further work would need to be done to ascertain whether type III

ought to be split into type IIIa and IIIb. An alternative suggestion would be an attempt by craftspeople with limited resources attempting to shift objects from one category into another during the recycling process. This might result in objects gathering at the parameters of each group, but this would only be possible with an extremely controlled industry, or we might expect to see objects scattered across the entire range of tin contents.

4.4 *Early 1st millennium BCE Assyrian musical instruments*

Musical instruments, especially percussion instruments, represent a class of object for which we have a very specific knowledge of their use and can prioritise certain characteristic qualities in the material they are made of. Colour may be an important factor in the manufacture of musical instruments (their aesthetic value is not completely overridden), but the sonorous qualities of the material will be paramount. The group of twenty percussion instruments from the early 1st millennium BCE in Assyria, is therefore a good category of objects to use as a test case when looking at *perceptive categories*. Containers are also looked at as a comparative study, as they are often made by similar techniques, but have a less materially specific function.

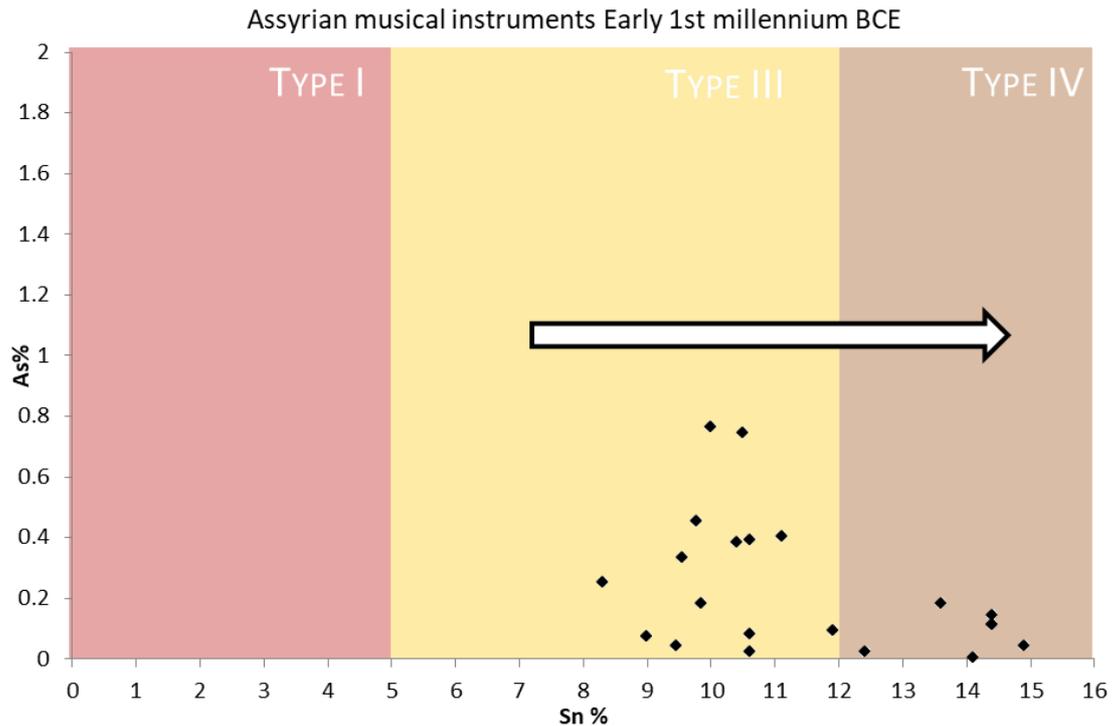


Figure 152: Early 1st millennium BCE Assyrian copper-base musical instrument assemblage overlaid by perceptive categories and charted by comparison of arsenic and tin

According to Kuijpers (2017) copper-alloy Type IV (12% – 20% Sn) is described as the range of tin which produces enhanced sonorous qualities, making it the perfect material for bells, drums, or other percussion instruments.

Figure 152 charts the tin and arsenic contents of 1st millennium BCE Assyrian percussion instruments against one another, and the *perceptive categories* are overlaid. There is a clear grouping of objects with generally low arsenic contents (<1% As) and between 8% and 15% Sn. They do not all fall within one perceptive category, but they do appear to have quite a strict composition. There is also the possibility that there are two separate groupings, with two stray objects with tin-contents of ~12% Sn. The first grouping is within type III, containing between 8% and 11% Sn, and the second possible grouping is in type IV, containing between 13.5% and 15% Sn. The group with lower tin frequently contains higher arsenic

quantities and could indicate the effect of cumulative alloying elements between groups.

The similarity in the effect of tin and arsenic composition on percussion instruments indicates two things. The first is that craftspeople and users were taking advantage of certain qualities of copper-alloys knowingly and for specific purposes. The second is that the proposed gap between 5% – 9% Sn and 9% and 12% Sn has again been indicated as relevant to the assemblages of Southwest Asia.

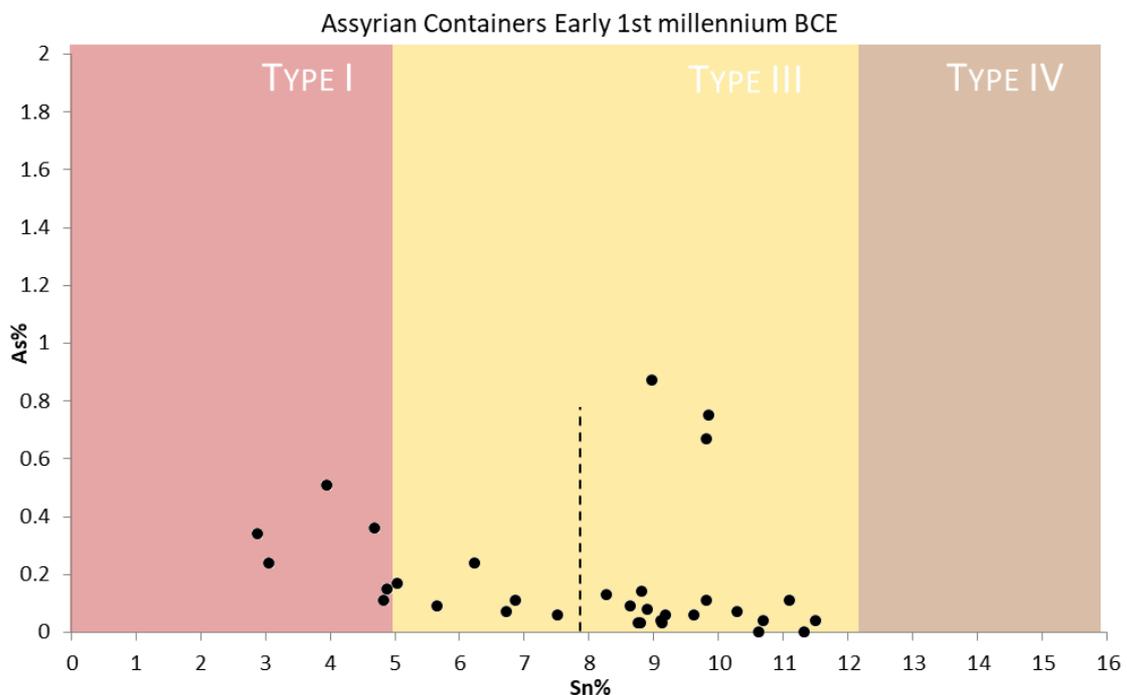


Figure 153: Early 1st millennium BCE Assyrian copper-base container assemblage overlaid by perceptive categories and charted by comparison of arsenic and tin

Looking briefly at Assyrian containers from the early 1st millennium BCE as a comparative example (Figure 153) we can see a much less strict range of tin content. This fits with the fact that the containers might be used for more varied functions, and specific qualities were not necessary in this group of artefacts as they were for musical instruments. This indicates a separation of object type and

manufacturing technique – it represents a choice made by the manufacturer. We can also potentially see a separation of two type III groups at around 8% Sn.

Easier casting properties and malleability when hammering are both important qualities for sheet metal, and the preference for perceptive category type III would indicate the addition of tin had a functional purpose. However the preference for the higher yet more confined range of tin for percussion instruments indicates that sound qualities may have been enhanced by the introduction of slightly more tin. Containers on the other hand are a mix of ornamental and functional, and therefore only a rough range might have been required, with the brighter yellow colour of higher tin perhaps more aesthetically appropriate for containers more often on display. This distinction between two object types with similar manufacturing techniques would once again indicate that *perceptive categories*, perhaps influenced primarily by colour, were influential in the Assyrian metallurgical tradition.

5 Chapter Summary

Throughout shifting temporal and regional metallurgical traditions there does appear to be a rough adherence to ranges of alloying element content which fit broadly within the *perceptive categories*. The musical instruments really emphasise that recognition by colour was not necessarily the end focus, but that it could have influenced the metallurgists' ability to recognise certain attributes of

behaviour in the copper-alloy of choice. The weapons and accessories on Cyprus, on the other hand, suggest a focus on the aesthetic qualities of copper-alloys with a focus on ornamental objects more often made from yellow tin-bronze rather than red-copper. Whereas in the Southern Levant, during a period of political turmoil, the importance placed on weaponry (either for a symbolic show of strength or actual military objects) was carried through into the choice of material. If greater social value was placed on weapons, the most valuable and adaptable metal was therefore the one most suitable for purpose. The case of shaft-hole axes devoid of tin, and ridge-necked axes with a very limited range of tin, also indicate a separation of object types, though perhaps this also relies on some sort of value assessment, as the same distinction is not observed in flat axes and crescent axes.

Behavioural qualities of copper-alloy combinations, perhaps marked out and identified by colour, would appear to have been important to craftspeople. Though the ternary diagrams of colour produced by Radivojević *et al.* (2017) are a useful indication of what objects actually looked like, and therefore the possibility exists of grouping objects together based on aesthetic qualities, it produces a relationship between the current archaeologist and the object, rather than the relationship between ancient craftspeople or consumers with the object. Perceptive categories on the other hand can give us an insight into the people behind the material and allow us to potentially glimpse the reasoning behind technological choices or the lack of it, as well as how the objects might have been viewed or chosen by those who owned the objects. Though the method is another form of analysing percentages of elements, an endeavour that is often criticised for being too embedded within scientific reasoning for its own sake rather than social or

traditional importance, it allows a deeper form of meaning to be glimpsed from the numbers.

Chapter Eight: Conclusion

The purpose of this chapter is to summarise the advantages and disadvantages of the approaches covered throughout the previous chapters and assess the thesis as a body of work. In order to do this the following discussion firstly focusses on the main objectives outlined in the thesis introduction. It is assessed to what degree these objectives were met and whether the methodologies applied in the process were appropriate. The most important narratives from the bulk of this thesis are reiterated and discussed in terms of their success within the framework of the method, similarly any sections of the work which might have been better achieved by the application of another method or focus are also be addressed. The next section covers what prospects for further research these successes have brought forward. Finally the nature of large-scale data synthesis is reviewed and again assessed in terms of its suitability for the scrutiny of Southwest Asian metallurgy from the 8th millennium BCE to the 1st millennium BCE.

The over-riding aim of this thesis was to apply methodologies developed elsewhere in Eurasia to a collection of all published data from Southwest Asia from the earliest copper use to the beginning of the Iron Age. Though regions within Southwest Asia have frequently been studied in tandem and conclusions drawn surrounding the movement of copper and its alloys across the wider region, this is

the first body of work to apply aspects of the Oxford System and Perceptive Categories to all the data simultaneously. In certain respects this research aimed to test the universality of these approaches as it has included analysis of chemical data which was collected by multiple analytical techniques and traditions. The limitations of synthesising such data were addressed in Chapter Three.

The research aims and objectives will now be addressed and assessed in order:

- 1 Understand technological approach at the beginning of smelting and the inception of alloying

A benefit to the application of systematic techniques across such a large body of data has been the realisation of certain phenomena which have previously gone un-noticed or under-reported. The first consequence of this was the ability to consider the earliest objects within the contexts of the beginnings of smelting. The origins of such technologies have always been highly debated, and quite rightly had a focus on the collection of early smelting debris and equipment. However, within this database it became obvious that instances of 'early' metal were relatively common. Even alongside the possibility that many early copper objects were the result of native copper working, it has become evident that several objects could not have been produced without the development of smelting technology. The presence of quantities of tin or iron within the chemical composition are not compatible with native copper use, though the dating of these objects is not always secure. It has therefore been hypothesised that though larger

scale smelting operations appear to have been underway in the 5th millennium BCE the technology itself may have been developed at least as early as the 6th millennium BCE, and possibly even earlier, though in sporadic and isolated contexts (Chapter Five, section 1). Owing to the risks of overinterpreting the significance of individual objects, this section was necessarily cautious and limited to a broader discussion of contradictions in the literature and an outline of the earliest objects in the database.

Scrutiny of widespread copper objects and a fixed nomination for what is considered alloying has also allowed the perception of alloying traditions from the very beginning of smelting technology. Whether intentionally produced or not, the study of objects containing significant quantities of one or more extra elements is indicative of the ores in use and the technologies available to the ancient craftsman. The limitation of ancient metalsmiths to simple smelting of ores such as malachite can no longer be adhered to, as clearly other ores and minerals were finding their way into the process. By the 4th millennium BCE half the copper-base objects contained >1% of additional elements, frequently several, and there was no adherence to any one type, which might be expected if the skills of the craftspeople were as limited as once hypothesised (Chapter Five section 2).

This thesis has shown that from the 4th millennium BCE there was an explosion of mineral and possibly technological experimentation: early zinc-rich material could indicate aspects about closed crucible smelting; 4th millennium BCE iron-rich metal suggests changes in approach to smelting technology, a shift to a more intensive process; perhaps a consequence on greater reliance on lower grade ores or increasing demand for the material. If we tie this in with the extraordinary alloys

of the Southern Levant, which although always considered extraordinary, are now evidently unlike any other period of alloying seen before or since, indicate both a high level of curiosity and immense skill.

The relatively routine production of early copper-tin objects has also been revealed by the collection of this database (Chapter Five, Section 2.2). Occasionally in the 5th millennium BCE, but especially in the 4th millennium BCE tin-bronzes of varying tin content and often mixed with other alloying elements begin to appear across Southwest Asia. The main hotspot for such alloying was Anatolia, especially in the Mediterranean Region near a mountainous region with climate conditions conducive to the weathering of stannite. When studied with the application of Kuijpers' *perceptive categories*, it has been possible to attempt an assessment on the accidental or deliberate nature of such alloy smelting. The consistently low tin contents alongside the frequent presence of other alloying elements is highly suggestive of the smelting of polymetallic ores or a mixture of several different ores which have been co-smelted. Both options are interesting within the narrative of increased experimentation with material.

In the course of this research a possible theory has been developed regarding the colour blue associated not only with the various assaying tests of each of the alloying elements in use at the time, but also of various ores that can be used to produce them, even the blue colour of weathered stannite. It is possible that colour was not only significant in the recognition of the material which had been produced, but perhaps also in the transmission of knowledge or the scope of experimentation conducted across a very wide area (Chapter Five, section 2.1).

A limitation of this approach was encountered in the search for the effect of inter-regional communication on alloy use and patterns. Certain regions were clearly more prolific than others in terms of their alloy use, tin-bronze traditions, and smelting techniques, but the level to which communication played a part was not visible. Patterns of communication and trade could be seen in the data, for example the period of cultural expansion in the late 4th to early 3rd millennium BCE, and the 2nd millennium BCE switch from Oman copper to Cypriot copper use, cultural phenomena that have been well documented and researched. Here it was clear that the changes identified in the chemical data could be easily correlated with the wider historical and archaeological knowledge. Although in these instances it was not possible to provide much more to the individual debate, only to recognise it within the chemical data. Despite this the recognition of these aspects shows that the system is working and would be able to (were data sufficient) highlight the presence of similar patterns in periods and regions where our levels of knowledge are less well defined. This raises positive possibilities with reference to the Caucasus and its relationship as a bridge between north and south.

In terms of the specific regional focus, however, different methodologies may have been more applicable to the question. A good example of this is the question of arsenic-nickel-copper alloy in the Caucasus and neighbouring regions during the time of the Maikop and Kura-Araxes Cultures (Chapter Five, section 3). Though there appears to be some form of link between these alloys and either communication or cultural expansion, this methodology does not allow for closer scrutiny. A geologically and regionally focussed research project would have been able to include the regional ore sources of the regions in question, and knowledge

of the contemporary smelting operations. These would have enabled a better understanding of *why* arsenic-nickel appeared to link the regions and whether it was coincident or the movement of copper itself or transmission of knowledge. The study of presence or absence of alloying elements was not nuanced enough for this particular kind of research focus, and the scope of the thesis did not allow time for closer scrutiny. Though patterns were visible that could be placed within the wider context, they did not always provide a deeper understanding of those events.

2 Consider the circulation of tin and its effect on regional tradition

The aim to reassess the possibility of the Kestel mine as a Southwest Asian-wide source of tin by studying the patterns of local and pan-regional tin-bronze use was successful (Chapter Five, section 5). The universality of the approach and the narrowed focus on tin ubiquity allowed the whole period and region to be assessed equally. The additional presence of alloying elements within the composition, though relevant in the consideration of ore sources and technological approach to the material, would obscure the main objective. The simplification of the data to tin-bronze or unalloyed copper with a low threshold allowed for patterns of change and use to be assessed. Alongside, the actual content of tin in the tin-bronzes allowed for both a pattern of use to be witnessed and the direction of trade hypothesised. This thesis has indicated that if the Kestel mine was exploited for tin (the approach cannot answer any queries regarding the actual contents of

the mine) it could have been used to supply the West and Central Anatolia, but the tin-bronze traditions of neighbouring regions do not support its establishment as a major tin supply.

The nature of the trade and supply of tin from the 3rd millennium BCE to the 1st millennium BCE across Southwest Asia was studied in both Chapter Five and Chapter Six. One of the express research objectives was to ascertain in what form tin was traded and this was attempted by the application of copper groups from both the tin-bronze assemblages and the untinned copper assemblages (Chapter Six). Unfortunately the application of this method was not successful in order to understand Southwest Asian-wide access to tin but rather provided insights into the varied nature of tin trade between specific regions. The pattern of tin-bronze use between regions and the varying nature of inter-regional trade obscures the signal that exclusively refers to the form in which tin was traded. However, a comparison between mid-3rd millennium BCE tin-bronze traditions and those of the early 2nd millennium BCE (Chapter Six, section 2) did indicate whether tin was generally traded in metallic or ore form in the former. From the apparent addition of tin to the entire local copper composition it was possible to infer that unalloyed tin was arriving in different regions owing to its indiscriminate presence across all copper compositions, no matter the regional combination or ubiquity. In the late 3rd millennium BCE, but that trade in pre-alloyed tin-bronze was more common in the early 2nd millennium BCE

It was possible, by more focussed regional scrutiny, to follow the tin distributions within certain copper groups and match the tin signal to that of the remaining copper groups in use (Chapter Six, section 2.3). This allowed a glimpse into the

differing regional approaches to tin. For example the totally separate tin content distributions in arsenic-nickel tin-bronzes from Eastern Arabia to those in Mesopotamia in the late 3rd millennium BCE, could indicate that tin was not traded pre-alloyed between these regions. In comparison the similarity of the tin distributions between the tinned and untinned assemblages of late 3rd millennium BCE indicated an identical treatment of copper compositions, highly suggestive of access to unalloyed tin.

The method of matching copper groups of tin-bronze to untinned copper assemblages was successful in that it was possible to see patterns of change, and perhaps which regions which had less access to tin as a raw material at any given time. However the possibility of simultaneous trade in copper *alongside* the tin renders the signal of pre-alloyed tin-bronze versus separate tin material obscured. It did outline the varying nature and overall lack of cohesion with regards to tin trade – this potentially highlights differing traditions, trading contacts, and forms of trade (e.g. in finished objects rather than raw material). Tin traded from the east and mentioned on a wide scale, though clearly occurring, was not the only method of trading this resource. Regional approaches to recycling varied too. This method (alloying patterns and copper group patterns) did highlight the complete difference in approach to tin-bronze in the early 1st millennium BCE. After the collapse of the Bronze Age there was a complete re-organisation of tin-bronze tradition, and it is also possible that access to tin changed, as most regions seem to predominantly have primary production signals, though recycling of material appears to have continued.

3 Recognise and appreciate the human activity behind, and interaction with, copper-base material

The focus on colour and Kuijpers' *perceptive categories* has allowed for access into the interaction that craftspeople and consumers had with the metal. In Chapter Seven there were clear groupings within these categories, which supports them. The most intriguing example of a clear difference in approach to the use of different tin quantities between objects, therefore presumably based on the perceptible difference in behavioural qualities of the material, was evident in the Northern Mesopotamian early 1st millennium BCE assemblage (Chapter Seven, section 4.4). The use of higher quantities of tin in the percussion instruments, which grouped at higher end of type III (5 – 12% Sn) and the lower end of type IV (12 – 20% Sn) which is known for its sonorous qualities, was evident. It was further confirmed by the addition of less tin to the vessels, the quantities of which were at the lower end of type III (5-12% Sn) and higher end of type I (<5% Sn). This gives us some insight into the manipulation of the material by the craftspeople specifically focussed on the purpose for which the objects would be put to use. A very specific composition was also visible from ridge-necked axes from Mahmatlar in West and Central Anatolia in the mid-3rd millennium BCE (Chapter Seven, section 4.1). These objects appear to have been made with a specific composition of tin in mind or were all made contemporaneously in the same location.

Despite the fascinating stories of human behaviour that this methodology has produced, it is the application of these *perceptive categories* to wider technological questions that have been the most profitable. The combination of perceptive levels

of arsenic paired with experimental indications of a minimum limit to refine out iron, have shown potential for the discussion of the addition of speiss in the production of arsenical-bronze (Chapter Five, section 8.1). This work is in very preliminary and simplistic stages and has relied on the assumption that the *intention* was to produce a perceivably different material from unalloyed copper. This has a whiff of technological determinism about it. However the application of both these methods has enabled discussion of the copper assemblage throughout Southwest Asia in terms of recognisable traces of a debated additional material. The initial reaction has been that if speiss was added to copper, as it appears it must have been in Iran, it was not done in a routine or widespread fashion across the remainder of Southwest Asia. The signal is not contrary to the possibility of traded Iranian material.

An unfortunate limitation in the *perceptive category* methodology which renders it slightly unsuitable for application to Southwest Asian data is the lack of knowledge regarding the cumulative effects of alloying elements on the behaviour and aesthetic properties of copper. The data from this region has numerous alloy types of widely varying quantities. There are also more alloying elements present within this data which would undoubtedly have an effect on the perceptive qualities of material than the collection of 'corrupting elements' included in that methodology.

4 Overall assessment

Overall large-scale synthesis of a wide range of data has been successful in highlighting specific areas that require a deeper research focus. It has also highlighted the weight placed on certain regions and time periods – the lack of focus on 2nd millennium BCE Mesopotamian copper work not only obscures patterns of trade and technology, but it over emphasises the copper traditions of the preceding period in comparison to other regional use. The application of the Oxford System, and to a certain extent the Perceptive Category methodology, to large-scale data has at once supported their practicality as a diagnostic tool, but also demonstrated that they cannot provide answers in and of themselves. The scale has also had limitations in the fact that though understanding the flow of copper is possible across vast swathes of land and disparate cultures, it necessarily neglects those regions which do not consistently fit into the wider picture owing to their positions on the outskirts. The Caucasus, Cyprus and the Southern Levant, for example, though discussed in terms of relation and conformity to the wider application of copper technology, have not been discussed in their own right. Undeniably these regions are to some extent the most important, as it is via the borders of Southwest Asia that some materials are believed to originate. However much has no doubt been missed in varying regional developments. In the case of the Caucasus the frequent dislocation from wider patterns and trends of tradition has highlighted periods of cultural isolation. With respect to the Southern Levant and Cyprus, their incorporation into the wider Mediterranean traditions has also somewhat limited their place in the discussion of Southwest Asian systems.

As a process with which to see patterns of change it is perhaps not surprising that methodologies such as these are most successful when applied to times of change or disruption. In this sense large-scale synthesis of data has been most successful in the assemblages of the 4th millennium BCE, the 3rd millennium BCE and in highlighting the visible difference at the start of the 1st millennium BCE. The universality of the approach is somewhat diminished by the fact that its use as a diagnostic tool with which to then exert further focus on more regional aspects of production is more successful than the ability to pinpoint wider phenomena occurring throughout time.

5 Further research

Understanding the cumulative effects of alloying elements, and further research into the effects of iron and zinc on copper, is a vital aspect through which we will begin to understand human approach and interaction with copper-base material. The diverse nature of copper-alloys from the 8th millennium BCE onwards across Southwest Asia is uniquely interesting in terms of experimentation and skill, however understanding recycling traditions or the purpose behind the manufacturing process is obscured owing to the fact that we cannot understand the properties (visual and behavioural) of all the materials in use. The scope for understanding ancient manufacturing techniques and production processes can also be better comprehended by a thorough knowledge of the effects of iron and zinc on copper.

Similarly an extension of the results of single-step smelting to include the possibility of ancient experimental smelting of random ore combinations would also be valuable in the study of the development of smelting technology. Scientific experimentation with a focus on blue-green ores may also provide knowledge about the transmission and regional development of smelting. This would also potentially open up an avenue into research of early tin. It needs to be ascertained whether these materials could be experimentally thrown together, and to discern what parameters drove the choices of early craftspeople in approach the material. A better understanding of the production and tradition of early tin manufacture may also provide insight to the development of tin-bronze technology or indeed may indicate that early copper-tin and later tin-bronze technologies were a separate phenomenon.

6 Concluding remarks

The legacy of surviving metalwork from ancient southwest Asia has afforded archaeologists astonishing works of art, vital pieces of evidence for cultural affinities, and a contribution to the complex typological chronology of one of the most important regions of the ancient world. The growing corpus of chemical data from this metalwork now forms part of this legacy. This thesis has attempted to review these data on a regional scale and contribute to our understanding the complex technological and cultural relationships in these regions over a period of 6000 years. It is necessarily coarse in temporal and geographical scale but provides a framework and a methodology within which more detailed regional studies can be located.

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Mid 3rd millennium BCE 'data map'

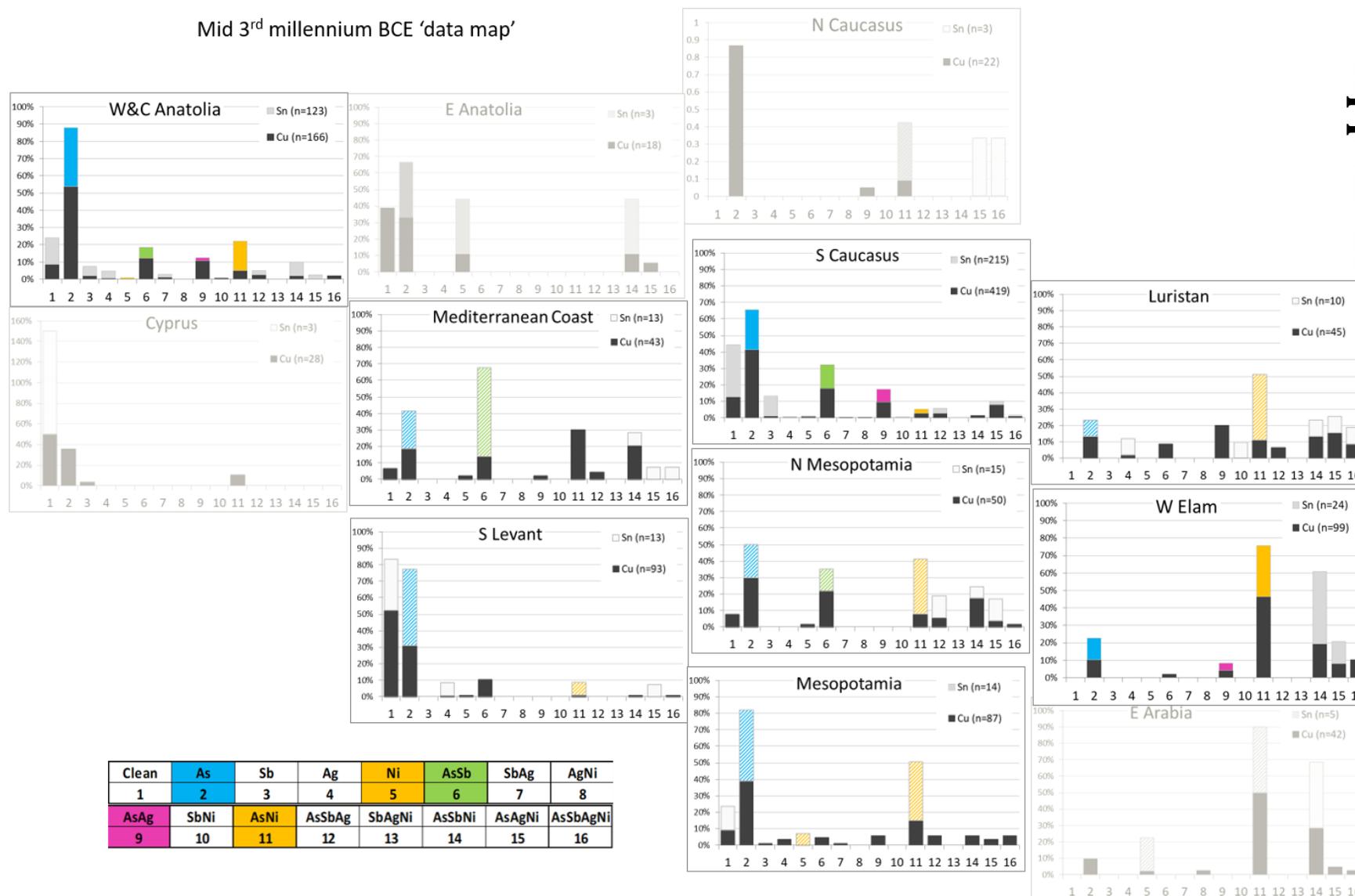


Figure 165: mid-3rd millennium BCE 'data map' depicting ubiquity of copper groups in untinned and tin-bronze copper assemblages, organised geographically

Late 3rd millennium BCE 'data map'

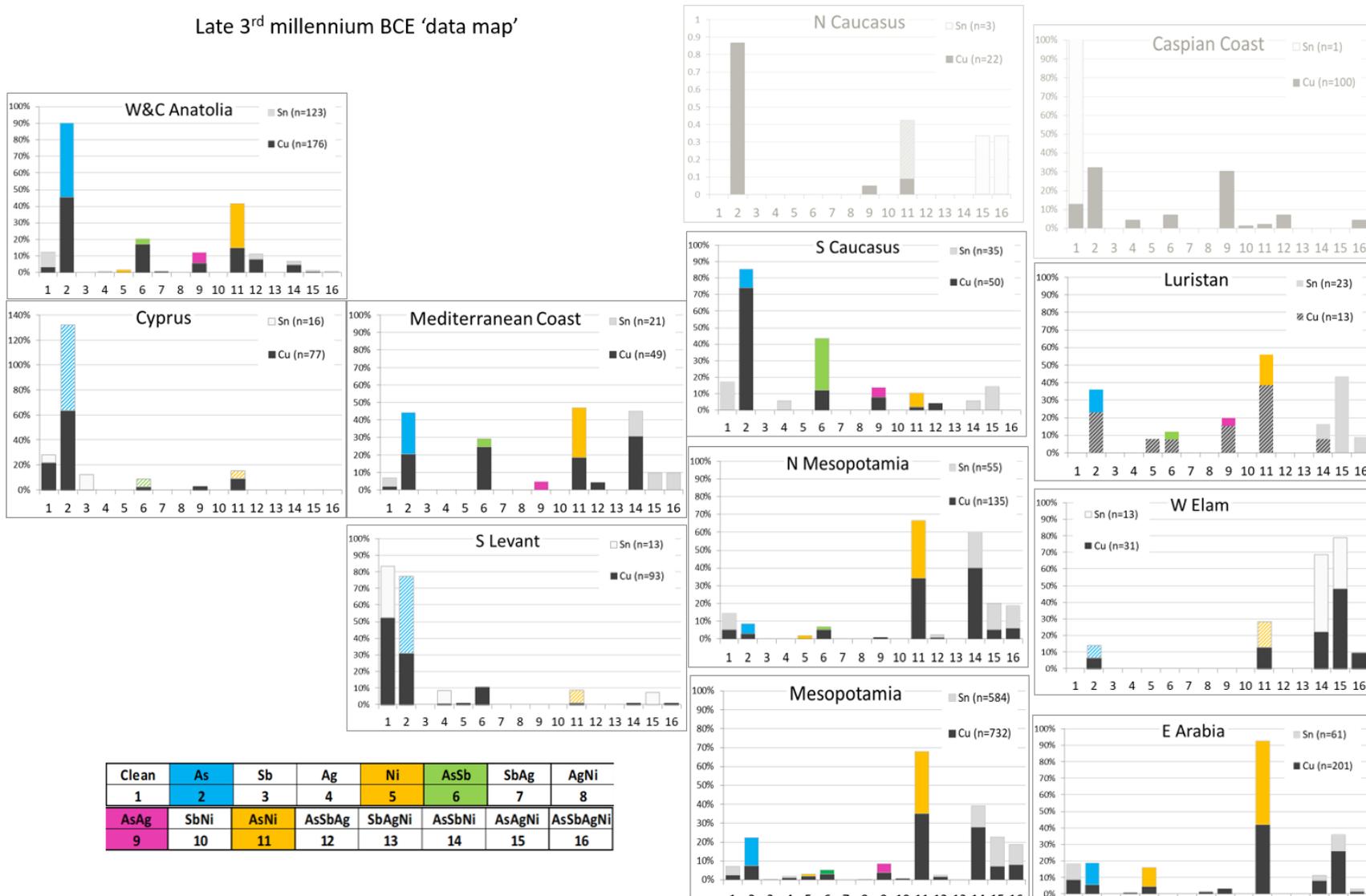


Figure 166 : late 3rd millennium BCE 'data map' depicting ubiquity of copper groups in untinned and tin-bronze copper assemblages, organised geographically

Early 2nd millennium BCE 'data map'

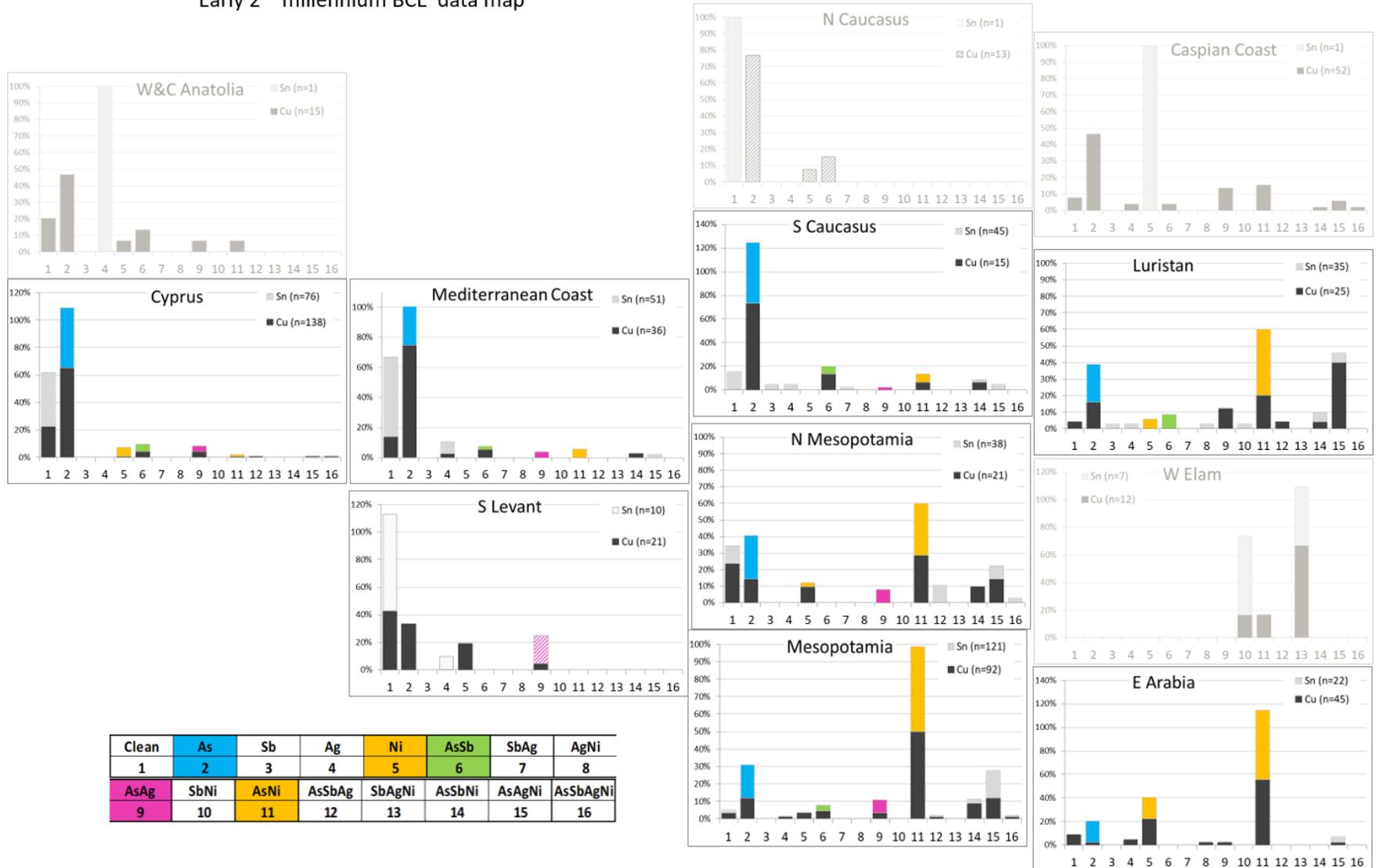
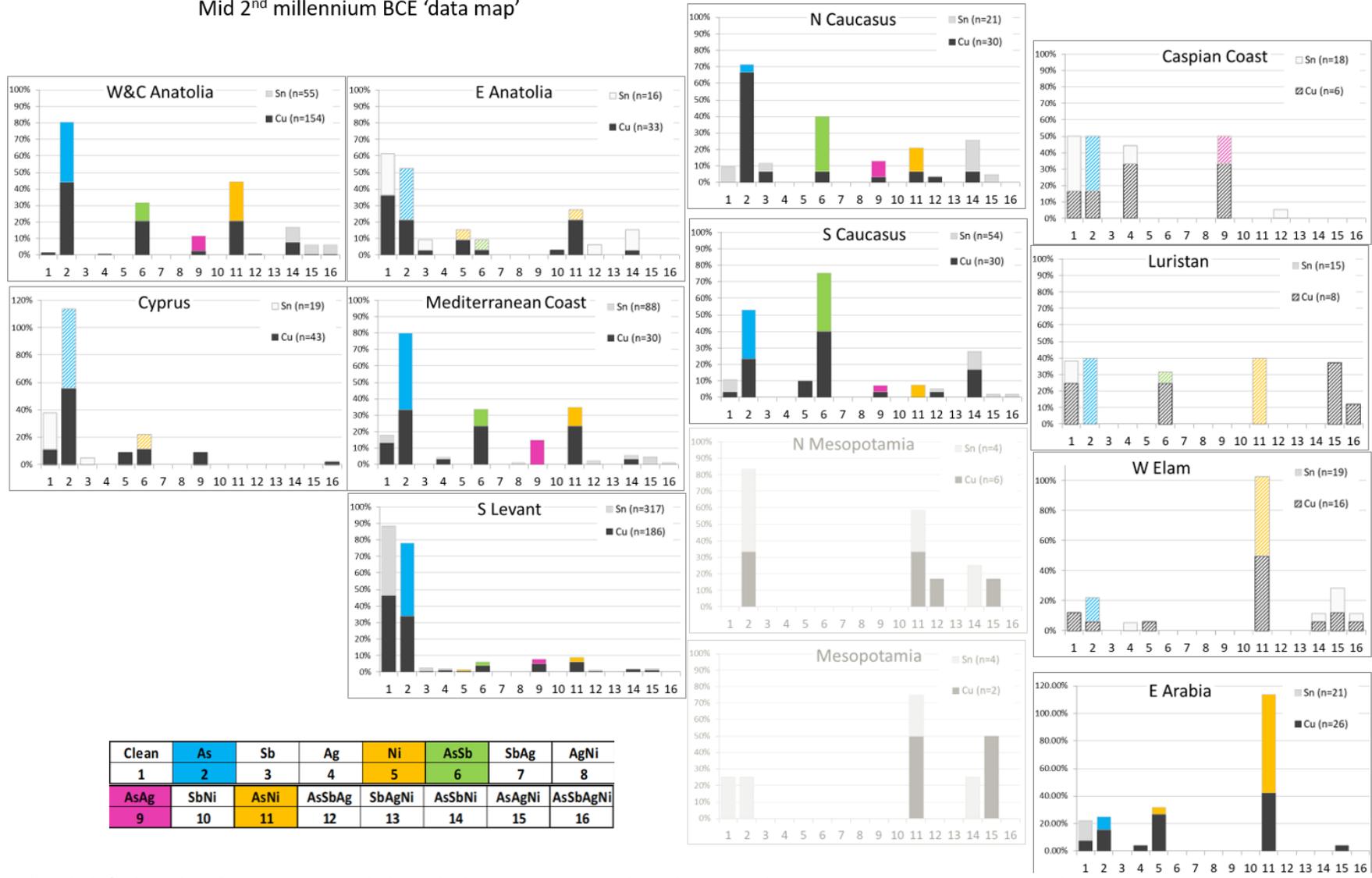


Figure 167: early 2nd millennium BCE 'data map' depicting ubiquity of copper groups in untinned and tin-bronze copper assemblages, organised geographically

Mid 2nd millennium BCE 'data map'



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Figure 168 : mid-2nd millennium BCE 'data map' depicting ubiquity of copper groups in untinned and tin-bronze copper assemblages, organised geographically

Late 2nd millennium BCE 'data map'

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Figure 169: late 2nd millennium BCE 'data map' depicting ubiquity of copper groups in untinned and tin-bronze copper assemblages, organised geographically

Early 1st millennium BCE 'data map'



Figure 170: early 1st millennium BCE 'data map' depicting ubiquity of copper groups in untinned and tin-bronze copper assemblages, organised geographically

