

# New tin mines and production sites near Kültepe in Turkey: a third-millennium BC highland production model

K. Aslıhan Yener<sup>1</sup>, Fikri Kulakoğlu<sup>2</sup>, Evren Yazgan<sup>3</sup>, Ryoichi Kontani<sup>4</sup>, Yuichi S. Hayakawa<sup>5</sup>, Joseph W. Lehner<sup>6</sup>, Gonca Dardeniz<sup>1</sup>, Güzel Öztürk<sup>2</sup>, Michael Johnson<sup>7</sup>, Ergun Kaptan<sup>3</sup> & Abdullah Hacıar<sup>8</sup>



*An unexpected new source of tin was recently located at Hisarcık, in the foothills of the Mount Erciyes volcano in the Kayseri Plain, close to the Bronze Age town of Kültepe, ancient Kanesh and home to a colony of Assyrian traders. Volcanoes in Turkey have always been associated with obsidian sources but were not known to be a major source of heavy metals, much less tin. X-ray fluorescence analyses of the Hisarcık ores revealed the presence of minerals suitable for the production of complex copper alloys, and sufficient tin and arsenic content to produce tin-bronze. These findings revise our understanding of bronze production in Anatolia in the third*

*millennium BC and demand a re-evaluation of Assyrian trade routes and the position of the Early Bronze Age societies of Anatolia within that network.*

**Keywords:** Kültepe Kanesh, Bolkardağ, Kestel, Anatolia, Bronze Age, pXRF, tin, trade networks

<sup>1</sup> Department of Archaeology and History of Art, Koç University, Istanbul, Turkey (Email: [akyener12@gmail.com](mailto:akyener12@gmail.com))

<sup>2</sup> Department of Archaeology, Ankara University, Turkey (Email: [kulakoglu@yahoo.com](mailto:kulakoglu@yahoo.com); [guzelozturk@gmail.com](mailto:guzelozturk@gmail.com))

<sup>3</sup> General Directorate of Mineral Research and Exploration (Retired), Turkey (Email: [evrenyazgan@hotmail.com](mailto:evrenyazgan@hotmail.com))

<sup>4</sup> Department of Contemporary Sociological Studies, Notre Dame Seishin University, Okayama, Japan (Email: [kontani.ryoichi@gmail.com](mailto:kontani.ryoichi@gmail.com))

<sup>5</sup> Center for Spatial Information Science, The University of Tokyo, Japan (Email: [hayakawa@csis.u-tokyo.ac.jp](mailto:hayakawa@csis.u-tokyo.ac.jp))

<sup>6</sup> Cotsen Institute of Archaeology, University of California, 308 Charles E Young Drive West, Los Angeles, CA 90024, USA (Email: [jwlehner@ucla.edu](mailto:jwlehner@ucla.edu))

<sup>7</sup> Department of Near Eastern Languages and Civilizations, 1155 East 58th Street, University of Chicago IL 60637, USA (Email: [mjohnson086@uchicago.edu](mailto:mjohnson086@uchicago.edu))

<sup>8</sup> Archaeology Department, Dokuz Eylül University, Izmir (Email: [abdullahhacar@hotmail.com](mailto:abdullahhacar@hotmail.com))

## Introduction

Prior to the identification of Anatolian tin, scholars argued that tin was necessarily traded into the region from Central Asia, Afghanistan or Europe for consumption in the Near East (see Muhly 1985, 1993; Stöllner *et al.* 2011). Rather than seeing early copper-tin alloys as products of long-distance exchange, we can now hypothesise that innovations in technology, which focused on the primary extraction of tin ores, allowed Early Bronze Age Anatolian alloys to be produced locally (Yener 2009). They were also probably traded through regional networks that linked these regions to other areas of production and consumption in Anatolia.

Evidence that emerged in 1987 prompted the publication, in *Antiquity*, of the first stannite tin occurrence at Bolkardağ in the Taurus Mountains of southern Turkey (Yener & Özbal 1987); this radically altered implications for the source of tin used in the production of high-grade bronzes, especially for the third millennium BC. Subsequent excavations and surveys at the Early Bronze Age (calibrated radiocarbon date 3240–3100 BC to 2870–2200 BC) Kestel tin mine and its contemporary production centre, Göltepe, established the existence of a multi-tiered production, exchange and consumption system (Yener 2000). Chronologically and functionally related, these two sites became the template for a highland production model of bronze manufacture for southern Anatolia in the Early Bronze Age.

The Early Bronze Age Anatolian highland production model (Yener 2000) is one that involves the two-tiered production of metal artefacts and the use of a diverse resource base. The first tier encompassed mining and smelting operations in the regions where rich ore deposits and forests were located, usually in the mountains. The second tier comprised lowland urban centres where the processed ores, in the form of either metal ingots or semi-processed materials, were refined, re-melted, alloyed and cast into various idiosyncratic metal assemblages. In addition to the emergence of this hierarchical organisation of production, adapted technologies were selected to use the highly variable polymetallic ores of the Anatolian highlands. For example, evidence from Arslantepe, located along the Upper Euphrates near to modern Malatya, provides excellent evidence for the use of local polymetallic ores through time. At Arslantepe Late Chalcolithic communities used ores with significant traces of antimony, arsenic, bismuth, nickel and silver; by the Early Bronze Age copper-iron sulphides dominated (Palmieri *et al.* 1999). Analysis of finished metal artefacts from this period, however, showed not only a predominance of arsenical copper but also the consumption of copper-silver and copper-arsenic-nickel (Hauptmann *et al.* 2002). A similar engagement with polymetallic ores and adapted technologies is evident in both highland Iran (Thornton 2009) and the Transcaucasus (Courcier 2014). Analysis of highland metallurgical debris and finished artefacts demonstrates that there was probably no one single optimal strategy in early metal production and, furthermore, that these production strategies represent the intentional use of a diverse resource base that was based on cultural knowledge.

This can be contrasted in part with our understanding of the organisation of metal production in the southern Levant. Thornton (2009) correctly characterised production strategies in this region as distinct from those of highland Anatolia and Iran; in the southern Levant Thornton describes the well-known shift from site-centred smelting and melting in the Chalcolithic and Early Bronze Age I (*c.* 4200–3000 BC) into a more

diversified, large-scale and centralised mode of production during the Early Bronze Age II–III (c. 3000–2300 BC). This shift also followed a pattern of production that took place outside of habitation areas where ingots of metal, rather than ores, were imported (see also Levy 1995; Golden *et al.* 2001; Genz & Hauptmann 2002; Levy *et al.* 2002). This reorganisation of production is similar to our understanding of metal production in Syro-Mesopotamia (Stech 1999), where peripheral highland resource areas supplied lowland consumers with a range of valuable metal products (Algaze 2008).

This important social shift during the Early Bronze Age II and III in the southern Levant also included changes in technology. Empirical evidence suggests that in earlier periods, smiths produced copper using crucible-based technologies and relatively homogenous iron-rich tile ores. Later, a shift towards the use of manganese-rich ores and furnace-based smelting allowed a larger scale production of relatively pure copper (Hauptmann *et al.* 1992: 7; Craddock 2001). It was also during this time that the first tin-bronzes were produced in the southern Levant, which indicates a formal alloying technology using imported primary tin and copper ingots (Hauptmann 2003). This contrasts somewhat with Anatolia, which saw a similar degree of diversification and hierarchical production; in Anatolia, however, a more diverse resource base extended the range of technological possibilities. Traditionally, bronze making was thought to segue naturally from using arsenic as the alloying material in the formative fourth to third millennia BC to the use of tin in the third millennium BC. According to text-based evidence, during the early second millennium BC tin was brought from the exotic lands of the east, potentially including Afghanistan and Central Asia, by caravans of Assyrian traders in search of gold and silver in Turkey (ancient Anatolia). Old Assyrian texts found at Kültepe testify to the existence during this period of a highly organised and sophisticated metals trade that possibly linked tin resources from central Asia (see Boroffka *et al.* 2002; Parzinger 2002) to central Anatolia by way of Babylonia and Assyria (Larsen 1976; Dercksen 1996, 2005). With the decades of research that followed, this simple picture was shown to be far from complete, especially for Early Bronze Age Anatolia.

During the late 1980s excavations at an Early Bronze Age tin mine at Kestel and its associated miners' village, Göltepe, in the central Taurus Mountains near Çamardı, Niğde, shed light on the origins of 5000-year-old tin bronze figurines, implements and crucible fragments previously found at Tell Judaidah in the Amuq valley, Hatay (Adriaens *et al.* 2002). Kestel mine was discovered by the Turkish Mining and Geological Directorate during mineralogical surveying in metal-rich zones of the Taurus; the results of subsequent archaeometallurgical investigations yielded the solution to a major enigma that had been puzzling scholars for decades—a source of the elusive tin of antiquity. The discovery of tin in Turkey attracted attention after its publication in *Science* (Yener *et al.* 1989) and much heated discussion followed (Muhly 1993). The realisation that multiple tin sources could have been exploited in the Near East was surprising, and the viability of extrapolating the sourcing of tin from second millennium BC contexts backwards into the earlier periods from c. 3000–2000 BC was called into question (Yener 2000, 2009).

Almost 30 years after the first publication, an archaeometallurgy survey has been conducted by the authors documenting the sources and occurrences of tin in Turkey; the highland tin-production model has now been extended to include the Hisarcık-Kıranardı,

Kayseri Erciyes area north of the initial discovery of cassiterite reported in the Taurus range. This unexpected source of a polymetallic ore deposit of tin (cassiterite), combined with arsenic (yazganite), located in the foothills of the stratovolcano, Erciyes (Roman *Argaeus*) in the Kayseri Plain, 26km south of the site of Kültepe, has profound implications for defining a major production zone in the hinterland of the largest Early Bronze Age settlement in Central Anatolia, ancient Kanesh (see Ministry of Culture and Tourism of Turkey website 2013). The development and exploitation of local and exotic ore bodies for the production of copper alloys by these third-millennium BC polities could be viewed as one of the magnets attracting Assyrian merchants in the second millennium BC.

## The discovery of the Hisarcık deposits

The Hisarcık cassiterite deposits were discovered by the General Directorate of Mineral Research and Exploration, specifically by geologist Evren Yazgan (Pehlivan *et al.* 2005; Yazgan 2005). Cassiterite was observed together with other oxides of iron and arsenic on the north-east slopes of Erciyes Dağ near modern Hisarcık and Zincidere in the province of Kayseri. The tin is unevenly mineralised inside pyroclastic rocks with acid composition formed by volcanic emissions ejected into the atmosphere, which then settled as bedded deposits, forming the foundations for long ridges such as Senir Sırtı (Figure 1) where scores of mining galleries were located. These ridges formed through seasonal erosion by intermittent streams, leaving in some places exposed rocky outcroppings (Figure 2). The evidence clearly indicates a complex relationship between the tin and the volcano, Erciyes (Figure 3). Archaeologists generally associated volcanoes in Turkey with obsidian sources; they were not known to be a source of metal ores, much less tin.

The iron-tin-arsenic ores were deposited in fumaroles within soft, easily carved material, allowing the mineral to be readily extracted, even with antler and horn. The new mineral ( $\text{NaFe}^{3+}_2(\text{Mg, Mn})(\text{AsO}_4)_3 \text{H}_2\text{O}$ ) was named yazganite after Evren Yazgan who discovered it. This mineral is unique to the andesitic volcanic complex, occurring in association with tridymite, hematite, cassiterite, magnetite, orpiment and realgar (Sarp & Cerny 2005). Independent analyses of the ore deposits near Hisarcık (Yalçın & Özbal 2009) confirmed the presence of tin in the still extant occurrences. The Erciyes volcanic rocks present a petrographic composition that changes from a basalt to basaltic andesite, andesite, dacite or rhyolite. The illustrated samples bearing cassiterite and yazganite minerals (Figures 4 & 5) come from the edges of fissures in the porphyric pyroxene andesitic rocks at Senir Sırtı. At Senir Sırtı these fissures were developed as near-surface extension fractures on the north-western and south-eastern sides during the Upper Pliocene. Cassiterite, yazganite, hematite and tridymite mineral paragenesis have developed on the cavity walls as coating materials in the near-surface open fractures. According to fluid inclusions studies, the common formation temperature for cassiterite and yazganite is between 460–580° C. Four hundred degrees Celsius is a critical temperature for the hydrothermal solutions; above 400° C all of the aqueous solutions transform in a gaseous phase (Yazgan in press). The metallic elements Sn (tin), As (arsenic), Fe (iron) and Mg (magnesium) are transported with halogen group elements F (fluorine), Cl (chlorine), Br (bromine) and I (iodine) in the fumarolian gaseous phase, which is why the cassiterite and yazganite minerals form on the cavity walls as coating





Figure 1. Topographical map of Senir Sirtı; contour intervals at 10m; map by Y.S. Hayakawa.

materials. Oxides form during the gaseous phase and deposit, presumably upon cooling at near surface temperatures. Similar shallow levels of tin-mineralisation emplacement with close associations with stratovolcanic processes were also observed in Bolivia (Sillitoe *et al.* 1975). It is important to emphasise that unlike the Kestel mine, many of the Hisarcık deposits are not vein-type deposits, but are more superficially deposited on the interior surfaces of the fumeroles and fissures; those observed at Zincidere are the exception. The natural exposure of these fissures would have enabled extraction of the ore deposits without the time- and energy-intensive mining technologies associated with extracting ores from veins in hard host rocks.

In 2013 as part of the Kültepe survey and excavations, investigations began at the second tin source on the foothills of the volcano Erciyes at Hisarcık and Zincidere. A portable X-ray fluorescence analyser was used alongside the survey efforts to identify the presence or absence of major ore types rapidly. Semi-quantitative analysis of ores was conducted using an internally calibrated procedure developed for the compositional analysis of ores; this analysis was conducted using the instrument in mining mode, which is a suitable method for measuring major and minor concentrations of metal elements (for the basic limitations of current portable X-ray fluorescence technology, see Liritzis & Zacharias 2011). These new tools have also allowed the rapid identification and characterisation of complex ore



Figure 2. Gallery wall at Senir Sırtı Kerim household showing extracted zone and remnant arsenic, iron and tin oxide mineralisations; photograph by J.W. Lehner.

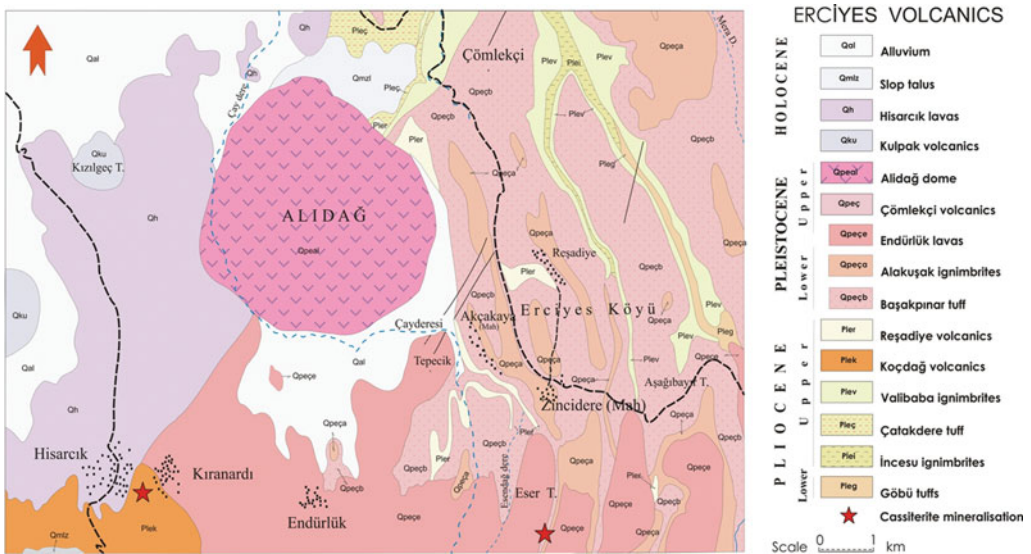


Figure 3. Simplified geological map of Senir Sırtı and vicinity, after Türkecan et al. 1998.



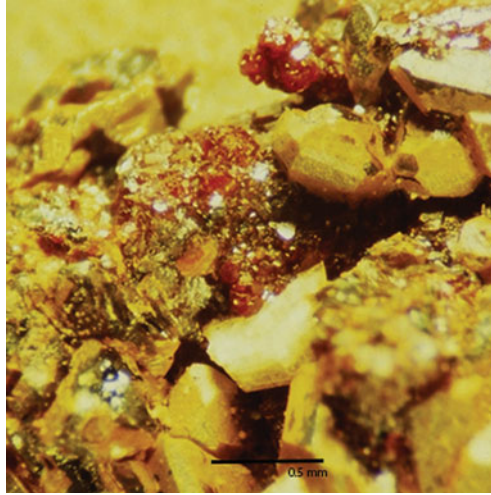


Figure 4. Cassiterite and yazganite minerals under a binocular microscope; photograph by E. Yazgan.

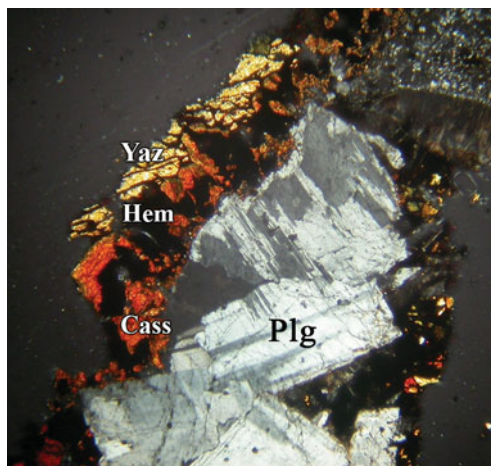


Figure 5. Cassiterite (Cass), hematite (Hem), and yazganite (Yaz) minerals on plagioclase (Plg) minerals of the host rock in thin section under a polarised light microscope; photograph by E. Yazgan.

bodies, and the discovery of new and hitherto unknown alloys and sophisticated crafting of ancient metal artefacts in museums. Multiple, semi-quantitative portable X-ray fluorescence analyses (in weight per cent, wt.%) of the Hisarcık ores at the Kerim household location yielded significant but variable values up to 90.7%  $\text{Fe}_2\text{O}_3$ , 20.4%  $\text{SnO}_2$  and 11.8% As, in addition to significant impurities of antimony, manganese and zinc (Table 1 & Figure 6).

The concurrence of tin and iron would have presented significant challenges to ancient smelters hoping to reduce tin metal from these ores. Given the similarity in the reducibility of iron and tin oxides, tin smelters would have faced a trade-off. Under low reducing conditions, slags rich in tin would be produced, effectively reducing the efficiency of the

Table 1. pXRF analyses of ore samples from Senir Sirtı Kerim household location (J.W. Lehner).

Sample number	Location	Fe <sub>2</sub> O <sub>3</sub> wt.%	SnO <sub>2</sub> wt.%	As ppm	Cu ppm	Ni ppm	Co ppm	Sb ppm	Pb ppm	Zn ppm	Mn ppm
Kerim1	outcropping	84.1	11.47	70	490	<350	<980	3470	<20	240	<4810
Kerim2	outcropping	69.5	0.97	30	360	<270	870	<140	<20	330	<3520
Kerim3	outcropping	20.2	10.50	117830	330	450	<580	15050	290	13060	54180
Kerim4	outcropping	49.4	13.61	200	200	<240	1290	5810	100	650	<3060
Kerim6	outcropping	90.7	2.85	120	2380	<100	<1000	<170	<20	260	<3990
Kerim7	gallery	5.85	1.80	570	130	150	<520	3130	60	180	<6220
Kerim8	gallery	61.9	20.44	35740	500	<850	<2300	19730	<150	510	38240



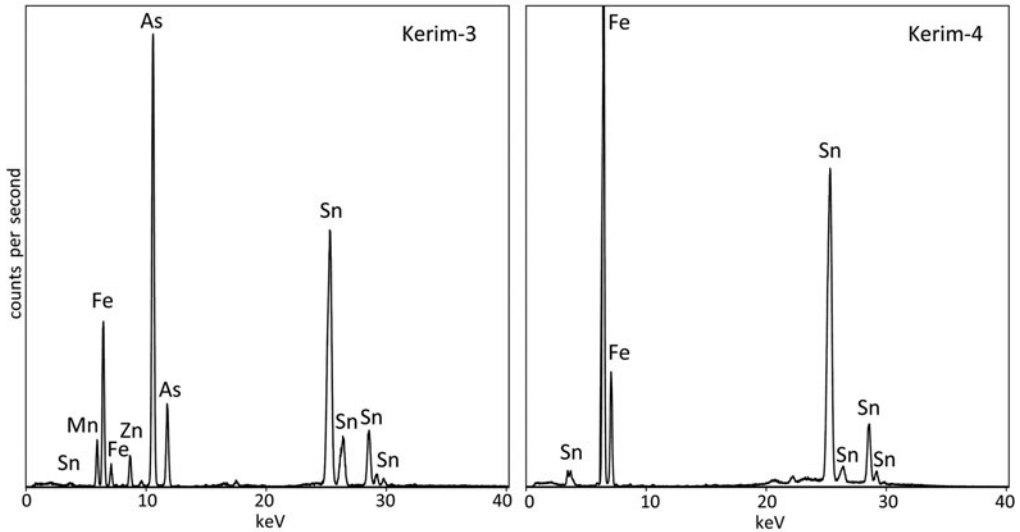


Figure 6. Spectra of pXRF analyses of ore samples from the Senir Sırtı Kerim household (J.W. Lehner).

smelt, even if metallic prills of tin could be retrieved. Conversely, to reduce the amount of tin-rich slag under high reducing conditions, significant quantities of iron would also be reduced into a product called hardhead (an iron-tin alloy) (Wright 1982; Grant 1994: 456; Smith 1996: 91). The Hisarcık ores could also have been used in co-smelting or mixed smelting operations to produce tin alloys directly through a primary smelting process. Rovira *et al.* 2009 demonstrated a simple co-smelting technique, experimenting by adding copper ores with cassiterite into a crucible to produce prills that were highly variable in tin (up to 81%). The pXRF analyses were confirmed by more precise measurements using a Field Emission Scanning Electron Microscope and Inductively Coupled Plasma Mass Spectrometer at KUYTAM (Surface Technologies Center) at Koç University in Istanbul.

Early Bronze Age II–III and even earlier Late Chalcolithic ceramics (Figure 7 & Figure 8: 1–6) found in association with the mining galleries shed light on the preliminary dating of the mines. Similar Red Slip wares, such as are seen in Figure 7 (7 & 9) and Figure 8 (3 & 4), stem from west Anatolian Early Bronze Age settlements. Red- and fine-burnished wares such as are shown in Figure 7 (4 & 6) and Figure 8 (5 & 6) were also excavated at Göltepe and dated to the Early Bronze Age II and III. Wares with mottling and dark or light burnishing, as seen in Figure 7 (1–3) and Figure 8 (1 & 2), are also known from the Late Chalcolithic to Early Bronze Age in this region. Soundings planned for the future will hopefully provide samples for radiocarbon dates. The diagnostic sherds were found on Senir Sırtı, one of the ridges that had multiple mining galleries. Comparable with archaeometallurgical finds at the Kestel mine and Göltepe (Kaptan 1995; Yener 2000, 2008), the ceramics as well as grinding stones were strewn on the surface near the gallery entrances, presumably as part of seasonal workshops for the initial processing of the ore at the mines.

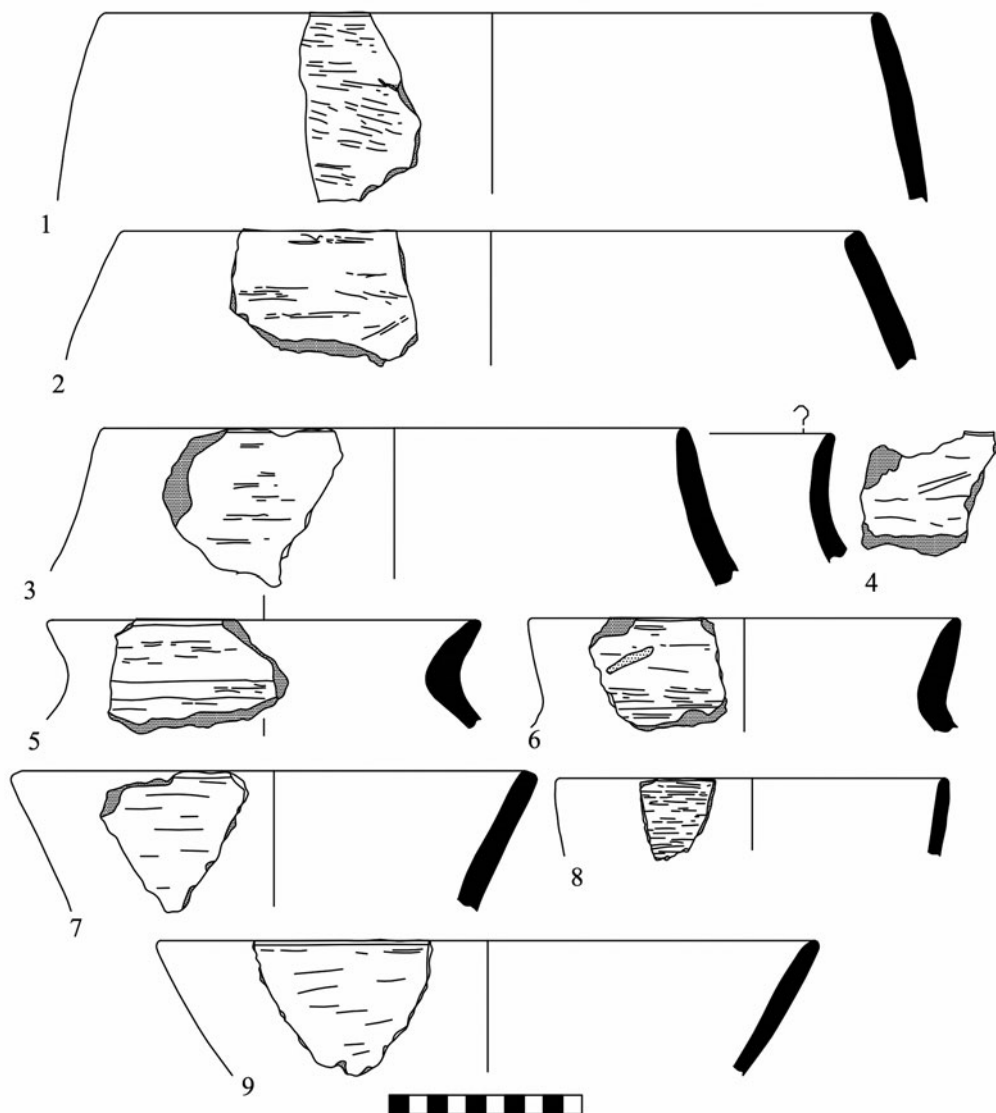


Figure 7. Late Chalcolithic and Early Bronze II–III ceramics from Senir Sirtı; drawing by H. Sudo, Y. Yamaguchi and A. Hacıar.

Predictably, akin to the linked and functionally related sites of Göltepe and Kestel Mine, 2km away from the mines on Senir Sirtı was a fortified processing site, Teknekayası Höyük (Figure 9), a major second-tier site. Located 24km from Kültepe, the mound measures 250 × 180m, and it was discovered during the Kayseri survey (Kontani *et al.* 2012, 2014a & b). A preliminary surface survey on this site in 2013 yielded Early Bronze Age II pottery together with Middle Bronze Age, Late Bronze Age and Iron Age pottery (Figure 10). Furthermore, ore-processing mortars, hammer stones, multi-hollow anvils and

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Figure 8. Ceramics from Senir Sirtı and Teknekayası; photograph by A. Hacıar.



Figure 9. Teknekayası processing site photograph viewed from the Senir Sirtı mines by G. Dardeniz.

grinding equipment found on the surface are components of the highland production model, and are therefore suggestive of a second-tier specialised processing and habitation site.

## Discussion

The highland production model is one that involves metals, precious not only in terms of economic value but also critical beyond calculation for their role in the negotiation of status

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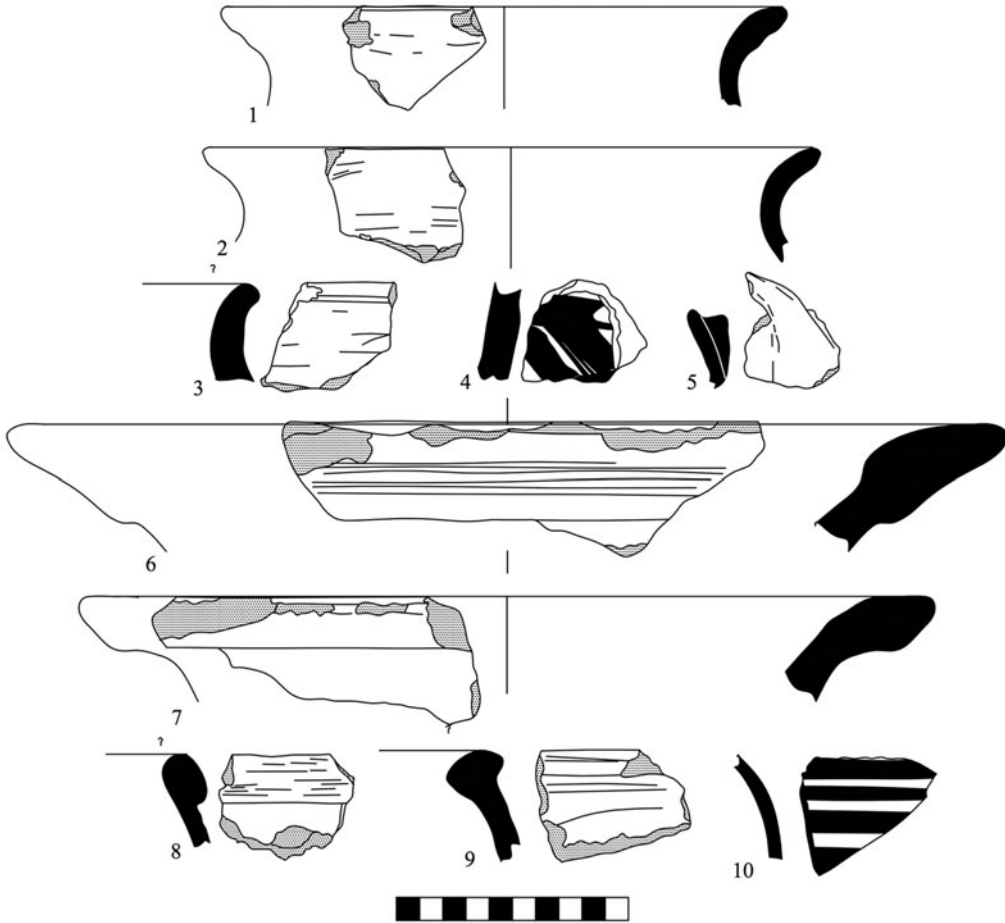


Figure 10. Surface ceramics from Teknekayasi; drawing by H. Sudo, Y. Yamaguchi and A. Hacıar.

and power, and their embodiment of a value-added commodity for trade. These new ways of making things and organising production reveal much about the nature of society. Recent research in ancient metallurgy and its sources have led to a better understanding of cultural relations, especially during the formative periods of metal technology and state formation in Anatolia. Once metal became locked into a cultural system as an indicator of wealth, disparities in access to labour and resources influenced how individuals operated within and between communities of producers and consumers. These relations often linked distant groups together into cooperative agreements, hence the Assyrian commercial network. Therefore, metal technologies are strategically placed in complex networks and institutions of production, exchange and consumption that effectively unite disparate highland resource areas and agricultural lowlands (Lehner & Yener 2014).

Clearly, the hinterland of the Early Bronze Age kingdom of Kanesh has provided extensive evidence of a rich and varied industrial resource for production and trade supplementing its



abundant agricultural yields from the Kayseri region. We use the term ‘kingdom’ advisedly; texts such as the later *šar tamhari*, ‘King of Battle’ legends of Akkadian kings Naram-Sin and Sargon (Özgüç 1986; Westenholz 1997), refer to a ‘king’ of Kanesh in the third millennium BC. Recent surface surveys (Kontani *et al.* 2014b) indicate that by the Early Bronze Age a three-tiered settlement hierarchy, indicative of a markedly complex settlement system, existed in proximity to the massive site of Kültepe. The three-tiered characteristic of the production sites near Kültepe-Kanesh is the relationship between mine, processing site and urban centre; this system of interconnected tiers suggests that some networks established in the Early Bronze Age were at least maintained and possibly strengthened in later periods. Furthermore, they were the backdrop of the subsequent Assyrian merchant trade. While the lower town (*karum*) of Kanesh was the location of multiple metal workshops in the second millennium BC (Özgüç 1955; Lehner 2014a), it is not yet known whether levels III and IV in the lower town were established prior to the Assyrian merchants’ presence, nor whether the Early Bronze Age levels on the mound contained metal workshops; these all remain future avenues for investigation (Kulakoğlu 2010, 2011; Kulakoğlu & Kangal 2010; Ezer 2014). Furthermore, the specific consequences for local bronze of the ready availability of Assyrian commercial tin in the second millennium BC remains a question for future investigation. Qualitative X-ray fluorescence analysis of a crucible with slaggy encrustations from the new mound excavations at Early Bronze Age Kanesh demonstrates that the crucible was used to process copper with tin and arsenic. These results are consistent with copper melting and the secondary production of copper alloys at the site. Primary metal products or scrap were therefore probably transported to the site for secondary production into finished objects. This pattern of production and trade is observed in later contexts at Kanesh and also at Late Bronze Age regional centres such as Hattusha and Alalakh.

Given the complex Middle Bronze Age copper alloys of Kanesh, which demonstrate a major grouping of copper-tin alloys with greater than 1% arsenic (Esin 1969; Lehner 2014a), it is increasingly likely that the knowledge of making bronzes using local sources of tin and arsenic was already established long before Assyrian merchants described the importation and trade of tin in economic texts. Understanding the existence and importance of such ternary alloys of bronze containing tin and arsenic, as well as other exotic alloys such as high-nickel- and high-antimony-bronzes, has taken on a new urgency. Analyses just completed by Lehner of third and second millennium BC copper alloys from Boğazköy-Hattuşa (Lehner 2014b; Lehner & Schachner in press) and Kültepe-Kanesh, as well as new analyses of Late Bronze Age Alalakh (Özbal 2006), and Tarsus bronzes (Kuruçayırlı & Özbal 2005; Kuruçayırlı 2007) have all revealed these unusual alloying combinations. Such ternary alloys have often been attributed to the re-melting of scrap metals, the collapse of trade networks, scarcity and other socio-economic reasons. Closer examination of the ore deposits has, however, revealed an alternative explanation: local production using the variations within myriad regional ore bodies. A similar observation has also been published by Radivojević *et al.* (2013) for the Balkans. They suggest that mixed smelting of stannite, fahlore and chalcopyrite produced compositionally variable copper-tin alloys *c.* 6500 BP. Here we see the importance of mixed smelting in the earliest dated copper-tin alloys. This study gives the survey and characterisation of smaller occurrences of tin

more urgency. Archaeological and geological survey of tin placer deposits in river valleys at Mount Cer in western Serbia, for example, shows a rise in possible Bronze Age settlements in locations particularly rich with tin placer ores (Huska *et al.* 2014), which further suggests that the localised production of tin-bronzes in south-east Europe is increasingly plausible.

## Conclusions

The suggestion that highland regions promote diversity is not a novel concept. Regional environments and resource distributions in the Anatolian highlands influenced diverse institutions of production and specialisation; the Hisarcık complex is only one example. The highland mining communities are one subset of such specialised institutions. These communities seemed to emerge with the greater demand for resources used in the creation of utilitarian and wealth objects during the mid-fourth millennium BC and especially the third millennium BC. The questions to research in the future are how these production zones were organised, managed and specifically how they developed into multiple tiers of production. Was it the result of emergent complexity or were they somehow coercively set in place? Furthermore, what were the exchange destinations of these raw materials and their impact on the consumers? For the more southern highland tin-production sites of Göltepe and Kestel, the second-tier destination was most likely the as yet unexcavated ancient city of Naḥita underneath modern Niğde and beyond the Taurus Mountains, southwards into the Cilician and the Amuq plains, where the Early Bronze I tin bronze figurines, crucibles and utensils of Judaidah appeared. We suggest that the destination of the Hisarcık ores and the products of the first-tier processing centres in the hinterland of the Erciyes volcano was the Early Bronze Age regional centre of Kanesh.

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