Metal consumption of a middle-range society in the late 3rd millennium BC Anatolia: A new socioeconomic approach

Gonca Dardeniz1*, Tayfun Yıldırım2

1 Department of Protohistory and Near Eastern Archaeology, Faculty of Letters, Istanbul University, Istanbul, Turkey, 2 Department of Protohistory and Near Eastern Archaeology, Faculty of Language History and Geography, Ankara University, Ankara, Turkey

* goncada rdenizarikan@istanbul.edu.tr, goncada rdemiz@gmail.com

Abstract

This article discusses the socioeconomic dynamics of metal consumption patterns in the 3rd millennium BC north-central Anatolian site of Resuloğlu (Çorum, Turkey). The socio-political structure of the site confirms a nonstate, socially complex community with a range of hierarchical and heterarchical expressions. This study presents the results of archaeological, compositional (n = 307), and isotopic (n = 45) analyses of the complete metal collection of Resuloğlu uncovered through two decades of systematic excavations with a well-established chronology. The elemental compositions of metal objects obtained with pXRF combined with lead isotope analysis denote a high diversity in alloy types and sources. The compositional analysis highlights the consumption of various binary and ternary alloys for different object types. The lead isotope ratios confirm the use of both in proximity to metallic sources and access to macro-regional trade extending from the Black Sea coast towards the Taurus Mountain range. The site appears as a part of linkages whereby goods and valuables were exchanged within decentralized networks of middle-range societies. The diversity in metal consumption suggests group-driven choices and networks rather than top-down control of social elites. This allows us to confront the conventional approach to the role of metals as the primary motivator for social complexity and inequality in all parts of the 3rd millennium BC Anatolia.

Introduction

Archaeology of the 3rd millennium BC (i.e., early bronze age) Anatolia suffers from over-ambitious readings of archaeological and analytical data to relate metal production and consumption to social inequality. The production and consumption of metals, specifically the alloy of copper and tin (hereafter bronze), are equated to hierarchical complex societies and political hierarchy. The publications have flooded with terms like elite, prestige, luxury, exotic, or strategic, even though there is little or no evidence to support such terminology. Wealth objects and prestige goods, which were defined as products only accessible by the elites via long-
distance trade or special craft products produced under the control of elite patrons [1: p. 10], have been used in ways improper to their anthropological definitions. Valuable metal objects were equalized to prestige goods, without confirmation of the presence of elites. White and Hamilton [2: p. 49–90] suggest that a centralized structure was not always necessary for production, and metals do not always lead to social inequality [2: p. 50–90]. This new model to interpret metallurgical practices in nonstate, decentralized societies offers a framework for the 3rd millennium BC Anatolian metallurgy.

The use of bronze has still widely accepted as one of the primary indices of complexity and advancement of Anatolian bronze age societies [e.g., 3]. This study hypothesizes that metal production and consumption patterns in the 3rd millennium BC Anatolian middle-range societies have not necessarily led to social inequality in every settlement. We argue that north-central Anatolia displays different lines of vertical and horizontal hierarchical relations and that diversity in socioeconomic systems has been overlooked.

Excavations at Resuloğlu (Çorum, Turkey), conducted between 2003–2019, uncovered both a settlement and a cemetery. The community of Resuloğlu represents primarily the end-users of metal products. The site provides us with the opportunity to discuss metal consumption and mobilization of commodities to obtain wealth and sustain control at the village level located in an environmentally diverse landscape. Resuloğlu offers a unique study area to reconsider the mainstream concept of the isolated and homogeneous character of Anatolian highland communities during the late 3rd millennium BC as well as to examine the role of metals in a middle-range society.

The significance of this study relies on the systematic assessment of Resuloğlu’s complete metal corpus. There are two main objectives: 1) to lay out detailed archaeological and analytical evidence on the metals, and 2) to position the data in the broader socio-economic context of the diversified trans-egalitarian communities of the 3rd millennium BC north-central Anatolia. This study drives data from multidisciplinary methods and interprets the information in the frame of diverse pathways of social complexity and inequality in middle-range societies. This approach presents important implications to understand the metal economics of nonstate societies during the late 3rd millennium BC in north-central Anatolia.

The archaeological context: Social inequality in the 3rd millennium BC north-central Anatolian middle-range societies

The present state of research on the 3rd millennium BC Anatolian archaeology has a series of major problems, among which is a lack of secure chronologies and a dearth of well-excavated and published sites [4]. North-central Anatolia is no exception. The first half of the 3rd millennium BC has left a little archaeological trace in the region. The latter half of the millennium on the contrary is documented through a rich material culture composed mainly of ceramics and metals. The majority of the material corpus from the region has been recovered from grave contexts, whereas evidence from domestic contexts is thin. Most of the sites are dated approximately to 2500/2400–2100/2050 BC through relative chronologies. The regional chronology is heavily dependent on ceramics and metal typologies and has several handicaps, along with the challenges related to burial contexts.

The majority of the late 3rd millennium BC archaeological sites located in north-central Anatolia are cemeteries such as Alaca Höyük (Çorum), Horoztepe (Tokat), Kalinkaya-Toptas-tepe (Çorum), Balıbağı (Çankırı), Göller (Amasya), and Oymağaç (Amasya) [5; 6 with references cited therein]. Yet the settlements associated with those cemeteries have mostly remained unidentified (Fig 1). While grave goods overarch the domestic material corpus, they could be representatives of some of the daily and utilitarian material corpora. A good example...
of how the material culture of a settlement has been represented in the cemetery area comes from the contemporaneous western Anatolian settlement of Demircihöyük with its coexisting cemetery of Sarıket. The Sarıket cemetery has pithoi from domestic contexts that have been used for burials, and utilitarian ceramics were found as grave goods [7].

In north-central Anatolia, associated settlements and cemetery areas are little known. Horoztepe, Balıbağ, and Kalınkaya-Toptaştepe [8] provided scattered architectural features of settlement areas; however, there is no clear evidence. Following this, more than half of the sites have been exposed during illegal activities causing a complete loss of contextual information. These major problems require further refining of the regional chronology, where possible, though any attribution to archaeological context should be done with caution.

The rich metal corpus of north-central Anatolia has attracted scholarly interest since the publication of metal artifacts from the 13 so-called ‘royal/princely graves’ of Alaca Höyük [9–12]. Mortuary traditions came into view also through funerary festivities such as specifically aligned cattle skulls and hooves on the shaft graves [e.g., 13]. Most of the discussion abounds about the symbolism and chemical composition of the extravagant metal objects such as sun-discs, zoomorphic and anthropomorphic figurines, jewelry, implements, and weapons made out of gold, silver, electrum, copper and its alloys, and even iron. Alas, only elaborate artifacts were given attention for archaeological and archaeometric analysis, preventing us from assessing a comprehensive understanding of corpora. Research focusing on the qualitative and quantitative characteristics of metal grave goods has overshadowed their social and behavioral context.
How were the north-central Anatolian societies organized during the late 3<sup>rd</sup> millennium BC? Was there really a ‘royalty’ to have the Alaca Höyük graves called after them? Were these groups all small-scale tribal and local [14, 15], or were they all based on elite-controlled, long-distance trade [16]? Could there be another way to evidence variety in societal evolution, which allows both options to be true? For example, could the social complexity of the region contain egalitarian groups with a range of inequality and hierarchical societies with egalitarian elements coexisting among these nonstate societies [17–20]?

The existing material evidence confirms the prosperity of the late 3<sup>rd</sup> millennium BC communities in north-central Anatolia. The richness of goods in graves or hoards at Alaca Höyük, Horoztepe, and Eskiyapar has been mostly explained as elite groups controlling production and trade. The archival or sacrificial values of such ostentatious metals and their legitimacy through consumption of unique items have been discussed as important elements of value systems [21–23]. Arguments relating metals to elites are mostly based on the presence of fully flourishing trading activity in the early 2<sup>nd</sup> millennium BC and the existence of certain nonlocal artifacts in Anatolia such as Syrian bottles, ivory, or lapis lazuli objects [4]. However, the illiteracy of Anatolia during the 3<sup>rd</sup> millennium BC prevents us from reconstructing the exact nature of this trade.

There is also a difference in societal types among the 3<sup>rd</sup> millennium BC communities. Some sites were considered as more prosperous (e.g., Alaca Höyük, Eskiyapar, Mahmatlar, Horoztepe) than others (e.g., Balıbaşı, Kalinkaya-Toptaştepe). Prosperity-related arguments were based on the relation between the production and consumption of bronze and centralized, hierarchical complex societies [e.g., 13, 24, 25]. However, not much has been hypothesized related to a political economy sponsoring this wealth and controlling the material flow. This gap in archaeological knowledge is especially true regarding small-scale, noncentralized village communities with some expressions of status inequality in the region, such as at Resuloğlu.

The concept of middle-range societies appears particularly useful to examine evolutionary societal types of the 3<sup>rd</sup> millennium BC north-central Anatolian communities. Egalitarian, noncentralized groups, formerly described as tribes, show a range of hierarchy and inequality [18, 26]. Centralized groups and even states demonstrate an egalitarian, heterarchical pattern [18, 27]. Middle-range societies, however, embrace diverse societal types, ranging between mobile bands and bureaucratic states [28]. This concept explains the social inequality of societies formerly defined as tribes or chiefdoms by showing that complexity does not show a linear pattern but has diversity among nonstate societies [27].

In the north-central Anatolian 3<sup>rd</sup> millennium BC, chiefdoms with leading elites controlling metal production and circulation have been accepted as the default societal type. Discussions abound around elites, prestige goods, control, and surplus. Yet not much has been explored regarding non-elite egalitarian groups that show elements of social inequality. In this study, we argue that there is variety in social inequality and hierarchical relations in the region during the second half of the 3<sup>rd</sup> millennium BC by deriving data from analytical methods. Resuloğlu, formerly described as chiefdom [5, 29, 30], demonstrates certain egalitarian and heterarchical elements that lead us to describe it properly as a middle-range society.

**Resuloğlu: Settlement, cemetery, social structure**

Resuloğlu is located in the Delice Valley of north-central Anatolia, at the northern edge of the modern city of Çorum and within the borders of Üğurludağ. The site is close to modern Çankırı and Ankara (Fig 1). It is a suite of sites consisting of settlements recorded as 1) northwest mound yielding late 4<sup>th</sup> millennium BC and a few late 3<sup>rd</sup> millennium BC sherds; 2) southeast
mound yielding late 3rd millennium BC deposits and a thin layer of 1st millennium BC; 3) north mound yielding fragmentary 3rd millennium BC evidence; 4) Resuloğlu II mound yielding fragmentary remains of the 1st millennium BC, and 5) the cemetery yielding 3rd millennium BC burials.

This suite of sites covers a long period from the late 4th to the 1st millennia BC, but any estimation of the territorial extent of Resuloğlu at a certain period seems difficult. Its greatest size was reached during the early 1st millennium BC and is estimated at 5 ha. The interruption in chronology and the fragmentary nature of archaeological evidence at the 4th millennium BC northwest mound and 1st millennium BC layers of the southeast mound prompted intensive research at the 3rd millennium BC layers of the southeast mound and the cemetery, which only covers the latter half of the period. Regarding the completion of the data, this research focuses only on this settlement and its contemporary cemetery (Fig 2). Therefore, what is referred hereafter as Resuloğlu is essentially the late 3rd millennium BC levels of the southeast mound.

The settlement dates to ca. 2500/2400–2100/2050 BC with relative chronology. Radiocarbon samples collected from different rooms and silos verify this interval (Table 1).

Two sub-phases, broadly identified as a late and an early phase, are distinguished based on ceramic and material evidence (Fig 3). Radiocarbon results from the later phase confirm the dating of 2200–2150 BC. The cemetery area is contemporaneous with the settlement based on

Table 1. Radiocarbon results of charcoal and carbonized grain samples from the Resuloğlu settlement. The analysis has been conducted at ETH Zurich and the Sarayköy Atomic Energy Institute in Ankara.

| Sample number       | Sample type                  | 14C result–1σ cal. BC | 14C result–2σ cal. BC |
|---------------------|------------------------------|-----------------------|-----------------------|
| ETH-42014 DK-10/101 | Charcoal                     | 2470–2290             | 2470–2340             |
| ZT 34. RO.12 Room 1 | Carbonized grains            | 2286–2042             | 2455–1975             |
| Room K (village-head’s house complex) | Charcoal | 2473–2235             | 2570–2195             |

https://doi.org/10.1371/journal.pone.0269189.t001
the material evidence recovered as parts of burial gifts. Based on the relative and absolute dating evidence, we can confidently propose a maximum occupational history of 400 years to the late 3rd millennium levels of Resuloğlu.

The settlement

Resuloğlu lies on the flat plain of a small hilltop in the hilly landscape of the central Pontides. The site overlooks the Delice River and Valley near the Kızılrmak River, the ancient Halys. The hilltop position provides the site with control over the valley from a secure standpoint. Additionally, the location connects well with both inner central Anatolia to the south and the Black Sea to the north. It also gives access towards Ankara at the west via a range of pathways. While this hilltop location presents a strategic advantage over the landscape and networks, it limits the size of the settlement to 0.35 ha [29; p. 587]. The cemetery covers 0.26 ha and is located on an opposite ridge with a separation of approximately 100–120 m today. The cemetery and the settlement might have been once connected. However, due to heavy erosion in this badland area, a cleft currently separates them.

The settlement provides invaluable information to investigate the site’s social complexity. Fortification walls and domestic architecture with three- to four-roomed houses that formed one- or two-story houses were found (Fig 4). At the southern end of the settlement, excavations yielded a 22-room house complex; with its own fortification and 30 silos of approximately 80 tons of storage [29, 31]. The materials found in this complex did not differ from the other houses. The excavation director Yıldırım [30] defined this sector as the residence of a chief; the presence of an aggrandizing individual based on the physical separation of the sector from the rest of the site. The labor invested in building fortification walls for the settlement and the multi-roomed complex along with massive silos should be encountered as a local-group level organization.
The material culture uncovered in the domestic structures includes local pottery, utilitarian tools of stone and bone, animal bones, and a few metal objects (Fig 3). Even though archaeological evidence suggests that textile production was part of the household economy, agricultural production stands as the pillar of Resuloglu’s economy. A significant architectural feature is a total of 64 circular silos with a capacity of 220 tons of grain [32] uncovered in association with or around the domestic houses (Fig 2). Stamp seals made of local stones (with only one example made of arsenical copper) were commonly found on the silo floors indicative of a certain level of control and ownership.

The cemetery

The cemetery consisted of 288 graves in four burial types: pithos, cist, jar, and simple inhumation (Fig 5). The majority of the graves were pithoi (Fig 5c). Burial gifts included ceramics, metal items, and beads made in various media [33, 34]. Funeral banquets appeared as a rare but known practice [13]. Cattle skulls or hooves left inside and outside of the graves showed similarities with the well-known examples from the graves at Alaca Höyük.

Types of burial gifts are similar to those found in domestic contexts at the settlement. Similar goods are widely known throughout the Halys Basin [33: p.8, Fig 11; 34]. The majority of
the graves contain metal artifacts. The metal grave goods display significant variation in terms of artifact typology. Jewelry such as bracelets, anklets, earrings, hair rings, beads, and torques are frequent. Pins are the most common type. Almost every burial contains at least one pin, possibly used to bind a cerement. Some burials were richer in numbers of metal objects, and some contain rare items like cups or daggers.

Social structure: Where are the elites?

Resuloglu’s village-head must be understood as an individual seeking power over desirable resources [35]. The capacity of the silos in this complex confirms this suggestion. Recent research predicted the total population of the settlement at 115 people [29: p.587], whose grain consumption would be approximately 40 tons [36, 37]. The existence of silos with a total capacity of 220 tons indicates that the population had stored almost an extra 180 tons of grain. It is possible that all the silos might not have been filled to full capacity every year due to natural fluctuations (i.e., precipitation) or other environmental perturbations (e.g., salinization). While these risks stand as reasons for a decrease in the production capacity, good seasons might well end with better yields of harvest. In a worst-case scenario, Resuloglu must have had at least 100 tons of grain, more than twice that they needed for exchange, confirming one of the subsistence economies as agriculture.

Resuloglu demonstrates a nonstate, agricultural society with an expression of hierarchy and egalitarianism that confirms its middle-range society concept. The archaeological and architectural remains at the settlement area support this. The existence of a separate residential area indicates a certain level of group hierarchy. However, defining the group settling in this private quarter as elites would be an overstatement. Silos in common areas, similarity in domestic house plans, and equality of material (e.g., stone tools, ceramics) in the house contexts designate a certain level of heterarchy. Archaeological evidence from the cemetery will support this.

Social differentiation has its roots in economically based power [38: p.56]. At Resuloglu, the primary subsistence is derived from agriculture, textile weaving, and husbandry. The household consumption of metals is limited to 12 utilitarian tools; the majority of tools were made of stone. The overarching consumption of metals as grave goods indicates that the surplus of staple commodities must have been exchanged or traded for metals, most likely to a certain extent under the control of the village-head. The variety in types and composition of metal grave goods demonstrates the extent of this give-and-take or trade system.

Taking the diversity of metal artifacts (e.g., axes, daggers, cups, beads, etc.) as a proxy of the varying personal status of individuals, such differences would imply a certain degree of social differentiation. For example, the only mace head from the site was recovered in a pithos grave belonging to an elderly female [39]. The rare occurrence of funerary banquets involving cattle skulls or hooves demonstrates the use of display in the burial rituals, which could be interpreted as a way to emphasize social status [40]. Still, there is no solid evidence to assign certain
burials to a leader or socially high-ranked persona. There is a certain degree of inequality; however, associating the metal-rich graves with the existence of elites would not fit the archaeological evidence from the domestic contexts either.

**Research context and materials**

The existing literature on the north-central Anatolian archaemetallurgy shows no doubt about the quality and quantity of metal artifacts in the region signaling the wealth and advanced technological skills of the ancient crafts. However, prestigious, symbolic, or exceptional artifacts have given priority to scientific analysis mostly overlooking utilitarian objects. Additionally, not much has been proposed regarding the socioeconomic system supporting such accumulation.

The existence of tin (>1 wt%), occasionally as high as ca. 20 wt%, on the so-called prestigious and symbolic corpora of metal grave goods, has fueled debates on the sources of tin [41, 42, with references]. Since the 1980s, this venue of debate—known as the ‘tin problem’ in the literature—has questioned whether tin was available in Anatolia. Today, the presence of Anatolian tin is unquestionable. Cassiterite, the tin oxide mineral (SnO$_2$), is available in Kestel (Niğde) and Hisarcık (Kayseri) as minor occurrences. These should have been available to ancient miners for a long time [42–45]. While Kestel’s tin was exploited and used during the 3rd millennium BC in its associated mining settlement of Göltepe [42, 43], archaeological evidence is pending for the systematic exploitation and use of Hisarcık’s tin.

The ostentatious metal corpora of the region have also prompted discussions on the identity of the craftspeople who were skilfully manufacturing such unique pieces. Local and regional schools for metalwork have been suggested for this preliterate period of Anatolia [46, 47]. Certain zones with rich polymetallic sources were proposed as suitable for extensive metal production [24]. Hattians, the local population of the Halys Basin during the second half of the 3rd millennium BC, have been suggested as skillful artisans of metalwork. Any discussions of the context of metal production or specialization will be inadequate, due to the archaeological context of these final products as grave goods [48: p. 154–155; 49]. Thus, this study does not propose any ideas in the context of metal production and specialization.

The systematic archaeological and archaeometric research conducted at Resuloğlu is unique in the sense of non-selective sampling. The first aim is to understand the metals used, alloy compositions, and the likely provenance of metals. Secondly, the investigation targets to detect any possible variations between the metal choices for the cemetery and the settlement. The third objective is to trace metal flow through trading networks. The ultimate goal of this study is to illuminate the life stories of metals in their socio-economic context.

Almost two decades of excavations at Resuloğlu have yielded approximately 400 metal objects and fragments. While beads constitute the majority of the assemblage, their fragile nature prevented conducting analytical research on many of them. 18 different artifact groups consisting of 152 pins, 40 beads, 21 earrings, 16 cups, 15 rings, 15 bracelets, 14 torques, 8 axes, 6 daggers, 5 needles, 5 anklets, 3 drills, 2 pendants, a seal, a mace head, a knife, a hair ring, and a chisel were analyzed in this study (Fig 6). The detailed information on the samples is listed in Table 2. All necessary permits were obtained for the described study, which complied with all relevant regulations from the Turkish Ministry of Culture and Tourism and the Çorum Museum.

**Analytical methodology**

**pXRF analysis**

Over the last decade, the use of pXRF has become increasingly common in the field of archaeology for the study of various types of artifacts and materials, as this analysis is effective in
Fig 6. Distribution of artifacts according to typologies.

https://doi.org/10.1371/journal.pone.0269189.g006
Table 2. The inventory numbers (excavation and/or museum numbers), object types, analysis point(s), typologies (where applicable), weighs, and alloy types of the Resuloğlu metal artifacts. (nd: not determined or inventory number not assigned; nm: weight not measured).

| Obj. | Excavation number | Museum Inventory number | Object type | Context | Analysis point | Typology (where applicable)/Notes | Weigh | Alloy type |
|------|-------------------|-------------------------|-------------|---------|----------------|-----------------------------------|-------|-----------|
| 1    | 2017              | nd                      | seal        | settlement | body  | square, geometric design          | nm    | Cu-As     |
| 2    | 6_15_2004         | 7516                    | pin         | cemetery   | body  |                                   | 6.75  | Cu-Pb     |
| 3    | 8_31_2005         | 7703                    | dagger      | cemetery   | blade |                                   | 77.9  | Cu-Sn     |
| 4    | 10_10_2003        | 7405                    | pin         | cemetery   | head, shaft |                                | 18.8  | Cu-As     |
| 5    | 10_19_2003        | 7414                    | bracelet    | cemetery   | body  |                                   | 127.3 | Cu-As-Sn  |
| 6    | 10_20_2003        | 7415                    | bracelet    | cemetery   | body  |                                   | 122.6 | Cu-Sn     |
| 7    | Ro.06/Etd.30      | 1064_1                  | bracelet    | cemetery   | body  |                                   | 117.95| Cu-Sn     |
| 8    | Ro.06/Etd.30      | 1064_2                  | bracelet    | cemetery   | body  |                                   | 122.9 | Cu-Sn     |
| 9    | 14_1_2008         | 8655                    | pin         | cemetery   | head, shaft |                                | 12.1  | Cu-As     |
| 10   | 14_2_2008         | 8656                    | pin         | cemetery   | head, shaft |                                | 4.1   | Cu-As     |
| 11   | 14_2_2009         | 8908                    | pin         | cemetery   | head, shaft |                                | 22.8  | Cu-Sn     |
| 12   | 14_3_2008         | 8657                    | pin         | cemetery   | head, shaft |                                | 22.5  | Cu-Sn     |
| 13   | 14_5_2009         | 8911_1                  | head        | cemetery   | body  | tubular                           | nm    | Cu-Sn     |
| 14   | 14_5_2009         | 8911_2                  | head        | cemetery   | body  | tubular                           | nm    | Cu-Sn     |
| 15   | 14_6_2008         | 8660_1                  | head        | cemetery   | body  | disc                              | nm    | Cu-Sn     |
| 16   | 14_6_2008         | 8660_2                  | head        | cemetery   | body  | disc                              | nm    | Cu-Sn     |
| 17   | 14_6_2008         | 8660_3                  | head        | cemetery   | body  | tubular                           | nm    | Cu-Sn     |
| 18   | 18_1_2007         | 8614_1                  | earring     | cemetery   | body  |                                   | total 2.15 | Cu-Ag-Au-Sb |
| 19   | 18_1_2007         | 8614_2                  | earring     | cemetery   | body  |                                   | total 2.15 | Cu-Ag-Au   |
| 20   | 18_12_2007        | 8625                    | earring     | cemetery   | gold leaf coating | stone with Au coating | nm    | Cu-Ag     |
| 21   | 18_25_2007        | 8638                    | pin         | cemetery   | head, shaft |                                | 16.25 | Cu-As-Sn  |
| 22   | 18_26_2007        | 8639                    | pin         | cemetery   | head, shaft |                                | 7.95  | Cu-Sn     |
| 23   | 18_3_2007         | 8616                    | pin         | cemetery   | head  |                                   | 13.8  | Cu-Sn     |
| 24   | 18_3_2007         | 8616                    | pin         | cemetery   | shaft |                                   | 13.8  | Cu-Sn-Pb  |
| 25   | 18_4_2007         | 8617                    | pin         | cemetery   | head, shaft |                                | 6.3   | Cu-As     |
| 26   | 6_11_2004         | 7512_1                  | head        | cemetery   | body  |                                   | nm    | Cu-Sn     |
| 27   | 6_11_2004         | 7512_2                  | head        | cemetery   | body  |                                   | nm    | Cu-Sn     |
| 28   | 6_12_2004         | 7513                    | pin         | cemetery   | head  |                                   | 17.35 | Cu         |
| 29   | 6_12_2004         | 7513                    | pin         | cemetery   | shaft |                                   | 17.35 | Cu-As-Sn  |
| 30   | 6_17_2004         | 7518                    | pin         | cemetery   | head, shaft |                                | 10.7  | Cu-Sn     |
| 31   | 6_18_2004         | 7519                    | pin         | cemetery   | head, shaft |                                | 17.2  | Cu-Sn     |
| 32   | 6_21_2004         | 7522_1                  | head        | cemetery   | body  | disc                              | nm    | Cu-Sn     |
| 33   | 6_21_2004         | 7522_2                  | head        | cemetery   | body  | disc                              | nm    | Cu-Sn     |
| 34   | 6_24_2004         | 7525                    | pin         | cemetery   | head, shaft |                                | 13.75 | Cu-Sn     |
| 35   | 6_26_2004         | 7527                    | pin         | cemetery   | head  |                                   | 12.8  | Cu-Sn     |
| 36   | 6_26_2004         | 7527                    | pin         | cemetery   | shaft |                                   | 12.8  | Cu         |
| 37   | 6_4_2004          | 7505_1                  | head        | cemetery   | body  | disc                              | nm    | Cu-Sn     |
| 38   | 6_4_2004          | 7505_2                  | head        | cemetery   | body  | disc                              | nm    | Cu-Sn     |
| 39   | 6_4_2004          | 7505_3                  | head        | cemetery   | body  | tubular                           | nm    | Cu-Sn     |
| 40   | 6_4_2004          | 7505_4                  | head        | cemetery   | body  | disc                              | nm    | Cu-Sn     |
| 41   | 6_8_2004          | 7509                    | pin         | cemetery   | head, shaft |                                | 15.05 | Cu-As     |
| 42   | 6_20_2004         | 7521                    | pin         | cemetery   | head, shaft |                                | 11.2  | Cu-Sn     |
| 43   | 6_29_2004         | 7530                    | axe         | cemetery   | body, blade |                                   | 174.7 | Cu-As     |
| 44   | nd                | 7602                    | pin         | cemetery   | head, shaft |                                | nm    | Cu-Sn     |

(Continued)
| Obj. Excavation number | Museum Inventory number | Object type | Context | Analysis point | Typology (where applicable)/Notes | Weigh | Alloy type |
|------------------------|-------------------------|-------------|---------|----------------|----------------------------------|-------|------------|
| 45 8_10_2005           | 7682                    | pin         | cemetery | head, shaft     |                                  | 16.3  | Cu-Sn      |
| 46 8_12_2005           | 7684                    | pin         | cemetery | head, shaft     |                                  | 9.45  | Cu-Ag      |
| 47 9_13_2006           | 7897_1                  | earring     | cemetery | head            |                                  | 2     | Cu-Ag-Au   |
| 48 9_13_2006           | 7897_2                  | earring     | cemetery | head            |                                  | 2     | Cu-Ag-Au   |
| 49 9_16_2006           | 7900                    | pin         | cemetery | head            |                                  | 36.9  | Cu-As-Sn   |
| 50 9_18_2006           | 7902                    | cup         | cemetery | body            |                                  | 42    | Cu-Ag      |
| 51 9_24_2006           | 7908_1                  | bead        | cemetery | body            | swastika                        | nm    | Au-Ag-As   |
| 52 9_24_2006           | 7908_2                  | bead        | cemetery | body            | tubular                         | nm    | Cu-Ag-Au   |
| 53 9_24_2006           | 7908_3                  | bead        | cemetery | body            | swastika                        | nm    | Au-Ag-As   |
| 54 9_24_2006           | 7908_4                  | bead        | cemetery | body            | tubular                         | nm    | Cu-Ag-Au   |
| 55 8_21_2005           | 7693                    | pin         | cemetery | head, shaft     |                                  | 8.8   | Cu-As      |
| 56 8_25_2005           | 7697_1                  | anklet      | cemetery | body            |                                  | 15.6  | Cu-Sn      |
| 57 8_25_2005           | 7697_2                  | anklet      | cemetery | body            |                                  | 26.05 | Cu-Sn-Pb   |
| 58 8_27_2005           | 7699_1                  | ring        | cemetery | body            |                                  | total 4.70 | Cu-Ag |
| 59 8_27_2005           | 7699_2                  | ring        | cemetery | body            |                                  | total 4.70 | Cu-Ag |
| 60 8_29_2005           | 7701                    | torque      | cemetery | body            |                                  | 11.1  | Cu-As-Ag   |
| 61 8_32_2005           | 7704_1                  | earring     | cemetery | head, earring_1 | total 5.60 | Cu-Ag |
| 62 8_32_2005           | 7704_2                  | earring     | cemetery | head, earring_2 | total 5.60 | Cu-Ag |
| 63 8_8_2005            | 7680_1                  | bead        | cemetery | body            | tubular                         | nm    | Cu-Sn      |
| 64 8_8_2005            | 7680_2                  | bead        | cemetery | body            | tubular                         | nm    | Cu-Sn      |
| 65 8_9_2005            | 7681                    | pin         | cemetery | head            |                                  | 8.4   | Cu-As      |
| 66 8_9_2005            | 7681                    | pin         | cemetery | shaft           |                                  | 8.4   | Cu-Sn      |
| 67 9_17_2006           | 7901                    | mace head   | cemetery | body            |                                  | 178.95 | Cu        |
| 68 9_26_2006           | 7910                    | cup         | cemetery | body            |                                  | 121.45 | Cu-Sn      |
| 69 9_6_2011            | 9104                    | pin         | settlement | head           |                                  | 6.95  | Cu-As      |
| 70 9_6_2011            | 9104                    | pin         | settlement | shaft           |                                  | 6.95  | Cu         |
| 71 9_7_2011            | 9105                    | pin         | cemetery  | head            |                                  | 6.25  | Cu         |
| 72 9_7_2011            | 9105                    | pin         | cemetery  | shaft           |                                  | 6.25  | Cu-As      |
| 73 9_8_2006            | 7892                    | pin         | cemetery  | head            |                                  | 13.65 | Cu-As      |
| 74 9_8_2006            | 7892                    | pin         | cemetery  | shaft           |                                  | 13.65 | Cu-As-Sn   |
| 75 9_8_2011            | 9107                    | pin         | settlement | shaft           |                                  | 6.6   | Cu-As      |
| 76 nd                  | Etd_1                   | axe         | cemetery  | blade, ridge    |                                  | >300  | Cu-Sn      |
| 77 Ro.05/Etd.3         | Etd_1002                | pin         | cemetery  | head, shaft     |                                  | 4.35  | Cu-As      |
| 78 Ro.05/Etd.4         | Etd_1003                | pin         | cemetery  | shaft           |                                  | 8.75  | Cu-Sn      |
| 79 Ro.05/Etd.5         | Etd_1004                | pin         | cemetery  | shaft           |                                  | 8.6   | Cu-Sn      |
| 80 Ro.05/Etd.6         | Etd_1005                | pin         | cemetery  | shaft           |                                  | 5.6   | Cu-As      |
| 81 Ro.05/Etd.7         | Etd_1006                | cup         | cemetery  | body            | fragment                        | 17.85 | Cu-Pb      |
| 82 Ro.05/Etd.8         | Etd_1007                | needle      | cemetery  | shaft           |                                  | 4.1   | Cu-Sn      |
| 83 Ro.05/Etd.9         | Etd_1008                | torque      | cemetery  | body            |                                  | 15.25 | Cu-Sn      |
| 84 Ro.05/Etd.10        | Etd_1009                | pin         | cemetery  | shaft           |                                  | 2.05  | Cu-As      |
| 85 Ro.05/Etd.11        | Etd_1011                | ring        | cemetery  | body            |                                  | nm    | Cu-Ag      |
| 86 Ro.05/Etd.14        | Etd_1013                | pin         | cemetery  | shaft           |                                  | 14.3  | Cu-Sn      |
| 87 Ro.05/Etd.16        | Etd_1015                | pin         | cemetery  | shaft           |                                  | 7.3   | Cu-Sn      |
| 88 Ro.05/Etd.18        | Etd_1017                | torque      | cemetery  | body            |                                  | 6.25  | Cu-Sn      |
| 89 Ro.05/Etd.19        | Etd_1018                | earring     | cemetery  | gold leaf coating |                       | nm    | Cu-As-Ag-Au |

(Continued)
| Obj. Excavation number | Museum Inventory number | Object type | Context | Analysis point | Typology (where applicable)/Notes | Weigh | Alloy type |
|-----------------------|-------------------------|-------------|---------|----------------|----------------------------------|-------|------------|
| 90 Ro.05/Etd.21        | Etd_1020                | bead        | cemetery | body           | nm                               | nm    | Cu-Sn      |
| 91 Ro.05/Etd.22        | Etd_1021                | ring        | cemetery | body           | 18.8                            |       | Cu-Sn      |
| 92 Ro.05/Etd.23        | Etd_1022                | cup         | cemetery | body           | fragment                        | 35.5  | Cu-Sn      |
| 93 Ro.05/Etd.24        | Etd_1023                | pin         | cemetery | shaft          | 22.1                            |       | Cu-Sn      |
| 94 Ro.05/Etd.26        | Etd_1025                | torque      | cemetery | body           | 97.25                           |       | Cu-Sn      |
| 95 Ro.05/Etd.27        | Etd_1026                | ring        | cemetery | body           | 75.95                           |       | Cu-Sn      |
| 96 Ro.05/Etd.28        | Etd_1027_1              | bracelet    | cemetery | body           | 79.95                           |       | Cu-Sn      |
| 97 Ro.05/Etd.28        | Etd_1027_2              | bracelet    | cemetery | body           | 63.9                            |       | Cu-Sn      |
| 98 Ro.05/Etd.29        | Etd_1028                | pin         | cemetery | shaft          | 7.2                             |       | Cu-Sn      |
| 99 Ro.05/Etd.31        | Etd_1030                | torque      | cemetery | body           | 66.7                            |       | Cu-Sn      |
| 100 Ro.05/Etd.32       | Etd_1031                | dagger      | cemetery | blade          | 10.15                           |       | Cu-As      |
| 101 Ro.05/Etd.34       | Etd_1033                | pin         | cemetery | shaft          | 2.8                             |       | Cu         |
| 102 Ro.07/Etd.1        | Etd_1079                | torque      | cemetery | body           | 47.25                           |       | Cu-Sn      |
| 103 Ro.07/Etd.2        | Etd_1080_1              | bracelet    | cemetery | body           | 39.75                           |       | Cu         |
| 104 Ro.07/Etd.2        | Etd_1080_2              | bracelet    | cemetery | body           | 47.3                            |       | Cu-Sn      |
| 105 Ro.07/Etd.3        | Etd_1081                | bead        | cemetery | body           | tubular                         | nm    | Cu-Sn      |
| 106 Ro.07/Etd.4        | Etd_1082                | axe         | cemetery | blade          | 9.1                             |       | Cu-As      |
| 107 Ro.07/Etd.5        | Etd_1083                | ring        | cemetery | body           | 2.65                            |       | Cu-As-Ag   |
| 108 Ro.07/Etd.6        | Etd_1084                | pin         | cemetery | shaft          | 9.1                             |       | Cu         |
| 109 Ro.07/Etd.7        | Etd_1085                | pin         | cemetery | head           | 7.5                             |       | Cu-Sn      |
| 110 Ro.07/Etd.8        | Etd_1086                | bead        | cemetery | body           | tubular                         | nm    | Cu-As      |
| 111 Ro.07/Etd.9        | Etd_1087                | earring     | cemetery | head           | 4.0                             |       | Cu-Sn      |
| 112 Ro.07/Etd.10       | Etd_1088_1              | earring     | cemetery | head           | total 2.85                      |       | Cu-Sn      |
| 113 Ro.07/Etd.10       | Etd_1088_2              | earring     | cemetery | head           | total 2.85                      |       | Cu-As-Sb   |
| 114 Ro.07/Etd.11       | Etd_1089                | pin         | cemetery | shaft          | 4.55                            |       | Cu-Sn      |
| 115 Ro.07/Etd.13       | Etd_1091                | pin         | cemetery | shaft          | 17.8                            |       | Cu-Sn      |
| 116 Ro.07/Etd.14       | Etd_1092                | pin         | cemetery | head           | 22.85                           |       | Cu-Sn      |
| 117 Ro.07/Etd.15       | Etd_1093                | pin         | cemetery | shaft          | 11.15                           |       | Cu-Sn      |
| 118 Ro.07/Etd.16       | Etd_1094                | pin         | cemetery | shaft          | 4.7                             |       | Cu-Sn      |
| 119 Ro.07/Etd.17       | Etd_1095                | pin         | cemetery | shaft          | 10.3                            |       | Cu-Sn      |
| 120 Ro.07/Etd.18       | Etd_1096_1              | bead        | cemetery | body           | tubular                         | nm    | Cu-Sn      |
| 121 Ro.07/Etd.18       | Etd_1096_2              | bead        | cemetery | body           | tubular                         | nm    | Cu-Sn      |
| 122 Ro.07/Etd.18       | Etd_1096_3              | bead        | cemetery | body           | ring                            | nm    | Cu-Sb      |
| 123 Ro.07/Etd.18       | Etd_1096_4              | bead        | cemetery | body           | disc                            | nm    | Cu-Sn      |
| 124 Ro.07/Etd.19       | Etd_1097                | pin         | cemetery | head           | 22.25                           |       | Cu-Sn      |
| 125 Ro.07/Etd.20       | Etd_1098                | pin         | cemetery | head           | vane- headed                     | 31.0  | Cu-Sn      |
| 126 Ro.07/Etd.21       | Etd_1099                | pin         | cemetery | head           | 26.85                           |       | Cu-Sn      |
| 127 M132               | Etd_11                  | pin         | cemetery | head           | 15.75                           |       | Cu-Sn      |
| 128 Ro.07/Etd.22       | Etd_1100                | cup         | cemetery | body           | fragment                        |       | Cu-Sn      |
| 129 Ro.07/Etd.23       | Etd_1101                | bracelet    | cemetery | body           | 29.9                            |       | Cu-Sn      |
| 130 Ro.07/Etd.24       | Etd_1102                | bracelet    | cemetery | body           | 10.55                           |       | Cu         |
| 131 Ro.07/Etd.25       | Etd_1103                | anklet      | cemetery | body           | 125.4                           |       | Cu-Sn      |
| 132 Ro.07/Etd.27       | Etd_1105                | pin         | cemetery | shaft          | 13.4                            |       | Cu-Sn      |
| 133 Ro.07/Etd.28       | Etd_1106                | pin         | cemetery | head, shaft    | 16.85                           |       | Cu-Sn      |
| 134 Ro.07/Etd.29       | Etd_1107                | pin         | cemetery | shaft          | 14.2                            |       | Cu-Sn      |
| 135 Ro.07/Etd.30       | Etd_1108                | pin         | cemetery | shaft, head    | 11.8                            |       | Cu-As-Sn   |
| Obj. | Excavation number | Museum Inventory number | Object type | Context | Analysis point | Typology (where applicable)/Notes | Weigh | Alloy type |
|------|-------------------|-------------------------|-------------|---------|----------------|-----------------------------------|-------|------------|
| 136  | Ro.07/Etd.32      | Etd_1110                | ring        | cemetery | body           |                                   | 58.3  | Cu-Sn      |
| 137  | Ro.07/Etd.33      | Etd_1111                | axe         | cemetery | body           |                                   | 147.9 | Cu-As      |
| 138  | Ro.07/Etd.34      | Etd_1112                | dagger      | cemetery | blade          |                                   | >300  | Cu-Sn      |
| 139  | Ro.07/Etd.35      | Etd_1113                | bead        | cemetery | body, tubular  | total of all beads in this inventory 4.45 | Cu-Sn |
| 140  | Ro.07/Etd.36      | Etd_1114                | pin         | cemetery | head           |                                   | 6.85  | Cu-Sn      |
| 141  | Ro.07/Etd.37      | Etd_1115                | torque      | cemetery | body           |                                   | 30.2  | Cu-Sn      |
| 142  | Ro.07/Etd.38      | Etd_1116                | pin         | cemetery | shaft          |                                   | 11.85 | Cu-Sn      |
| 143  | Ro.07/Etd.39      | Etd_1117                | pin         | cemetery | head           |                                   | 2.65  | Cu-As      |
| 144  | Ro.07/Etd.40      | Etd_1118                | pin         | cemetery | head           |                                   | 6.25  | Cu-As      |
| 145  | Ro.07/Etd.41      | Etd_1119                | bead        | cemetery | body, tubular  | nm                                 |       | Cu-Sn      |
| 146  | Ro.07/Etd.42      | Etd_1120                | pin         | cemetery | shaft          |                                   | 12.65 | Cu-Sn      |
| 147  | Ro.07/Etd.43      | Etd_1121                | bracelet    | cemetery | body           |                                   | 51.2  | Cu-As-Sn   |
| 148  | Ro.08/Etd.1       | Etd_1126_1              | anklet      | cemetery | body           |                                   | 196.05 | Cu-Sn   |
| 149  | Ro.08/Etd.1       | Etd_1126_2              | anklet      | cemetery | body           |                                   | 185.0 | Cu-Sn      |
| 150  | Ro.08/Etd.2       | Etd_1127_1              | bracelet    | cemetery | body           |                                   | 54.5  | Cu-Sn      |
| 151  | Ro.08/Etd.2       | Etd_1127_2              | bracelet    | cemetery | body           |                                   | 51.95 | Cu-Sn      |
| 152  | Ro.08/Etd.3       | Etd_1128_1              | pin         | cemetery | head           | total of 10 pins in this inventory 292.65 | Cu    |
| 153  | Ro.08/Etd.3       | Etd_1128_1              | pin         | cemetery | shaft          | total of 10 pins in this inventory 292.65 | Cu    |
| 154  | Ro.08/Etd.3       | Etd_1128_2              | pin         | cemetery | shaft          | total of 10 pins in this inventory 292.65 | Cu    |
| 155  | Ro.08/Etd.3       | Etd_1128_3              | pin         | cemetery | shaft          | total of 10 pins in this inventory 292.65 | Cu    |
| 156  | Ro.08/Etd.4       | Etd_1129                | pin         | cemetery | head           |                                   | 5.35  | Cu-As      |
| 157  | Ro.08/Etd.5       | Etd_1130                | needle      | cemetery | shaft          |                                   | 1.9   | Cu-As      |
| 158  | Ro.08/Etd.6       | Etd_1131                | pin         | cemetery | head, shaft    |                                   | 6.25  | Cu-Sn      |
| 159  | Ro.08/Etd.7       | Etd_1132                | pin         | cemetery | shaft          |                                   | 7.95  | Cu-Sn      |
| 160  | Ro.08/Etd.8       | Etd_1133                | pin         | cemetery | shaft          |                                   | 7.8   | Cu-Sn      |
| 161  | Ro.08/Etd.9       | Etd_1134                | pin         | cemetery | shaft          |                                   | 3.7   | Cu-As      |
| 162  | Ro.08/Etd.10      | Etd_1135                | pin         | cemetery | head, shaft    |                                   | 9.05  | Cu-Sn      |
| 163  | Ro.08/Etd.11      | Etd_1136                | pin         | cemetery | head, shaft    |                                   | 13.35 | Cu-Sn      |
| 164  | Ro.08/Etd.12      | Etd_1137                | pin         | cemetery | head, shaft    |                                   | 19.2  | Cu-Sn      |
| 165  | Ro.08/Etd.13      | Etd_1138                | torque      | cemetery | body           |                                   | 19.65 | Cu-Sn      |
| 166  | Ro.08/Etd.14      | Etd_1139                | dagger      | cemetery | blade          |                                   | 25.95 | Cu-Sn      |
| 167  | Ro.08/Etd.15      | Etd_1140                | knife       | cemetery | blade          |                                   | 20.15 | Cu-Sn      |
| 168  | Ro.08/Etd.16      | Etd_1141                | axe         | cemetery | blade          |                                   | 120.1 | Cu-As      |
| 169  | Ro.08/Etd.17      | Etd_1142                | pin         | cemetery | head           |                                   | 14.4  | Cu-Sn      |
| 170  | Ro.08/Etd.18      | Etd_1143                | cup         | cemetery | body           |                                   | 48.55 | Cu-Sn      |
| 171  | Ro.08/Etd.19      | Etd_1144                | pin         | cemetery | shaft          |                                   | 19.1  | Cu-Sn      |
| 172  | Ro.08/Etd.20      | Etd_1145                | pin         | cemetery | shaft          |                                   | 6.5   | Cu-Sn      |
| 173  | Ro.08/Etd.21      | Etd_1146                | pin         | cemetery | head           |                                   | 7.7   | Cu-As      |
| 174  | Ro.08/Etd.22      | Etd_1147                | pin         | cemetery | shaft          |                                   | 3.7   | Cu-As      |
| 175  | Ro.08/Etd.23      | Etd_1148                | torque      | cemetery | body           |                                   | 25.5  | Cu-Sn      |
| 176  | Ro.08/Etd.24      | Etd_1149                | torque      | cemetery | body           |                                   | 40.5  | Cu-Sn      |
| 177  | Ro.08/Etd.25      | Etd_1150                | earring     | cemetery | head           |                                   | 2.9   | Cu         | (Continued)
Table 2. (Continued)

| Obj. Excavation number | Museum Inventory number | Object type | Context | Analysis point | Typology (where applicable)/Notes | Weigh | Alloy type |
|------------------------|-------------------------|-------------|---------|----------------|-----------------------------------|-------|------------|
| 178 Ro.08/Etd.26       | Etd_1151_1              | ring        | cemetery | body           |                                   | total 2,3 Ag |          |
| 179 Ro.08/Etd.26       | Etd_1151_2              | ring        | cemetery | body           |                                   | total 2,3 Cu-Sn |          |
| 180 Ro.08/Etd.27       | Etd_1152                | ring        | cemetery | body           |                                   | 5.25 Cu-As |          |
| 181 Ro.08/Etd.28       | Etd_1153_1              | bead        | cemetery | body           | disc                              | total of all beads in this inventory 40.75 Cu-Sn |          |
| 182 Ro.08/Etd.28       | Etd_1153_2              | bead        | cemetery | body           | barrel                            | total of all beads in this inventory 40.75 Cu-Sn |          |
| 183 Ro.08/Etd.28       | Etd_1153_3              | bead        | cemetery | body           | tubular                           | total of all beads in this inventory 40.75 Cu-Sn |          |
| 184 Ro.08/Etd.29       | Etd_1154                | head        | cemetery | disc           |                                   | nm Cu-Sn |          |
| 185 Ro.08/Etd.30       | Etd_1155                | earring     | cemetery | head           |                                   | 5.35 Cu-As-Ag-Au |          |
| 186 Ro.08/Etd.30       | Etd_1155                | earring     | cemetery | shaft          |                                   | 5.35 Cu-As-Au |          |
| 187 Ro.08/Etd.31       | Etd_1156                | bead        | cemetery | body           | Ur-type                           | nm Cu-Ag-Au |          |
| 188 Ro.08/Etd.47       | Etd_1172                | drill?      | cemetery | shaft          |                                   | 4.55 Cu-As |          |
| 189 Ro.08/Etd.48       | Etd_1173                | cup         | cemetery | body           |                                   | 26.75 Cu-Sn |          |
| 190 Ro.09/Etd.21       | Etd_1194                | earring     | cemetery | head           |                                   | 2.8 Au-As |          |
| 191 Ro.09/Etd.22       | Etd_1195                | earring     | cemetery | gold leaf coating |                                   | 0.1 Cu-As-Ag-Au |          |
| 192 Ro.09/Etd.23       | Etd_1196                | pin         | cemetery | shaft          |                                   | 18.7 Cu-As-Sn |          |
| 193 Ro.09/Etd.25       | Etd_1198                | pin         | cemetery | head           |                                   | 15.0 Cu-Sn |          |
| 194 Ro.09/Etd.26       | Etd_1199                | pin         | cemetery | head           |                                   | 8.4 Cu-As |          |
| 195 Ro.06/M137         | Etd_12                  | pin         | cemetery | shaft          |                                   | 3.6 Cu |          |
| 196 Ro.09/Etd.27       | Etd_1200                | pin         | cemetery | head           |                                   | 21.55 Cu-Sn |          |
| 197 Ro.09/Etd.28       | Etd_1201                | pin         | cemetery | head           |                                   | 6.35 Cu-Sn |          |
| 198 Ro.09/Etd.29       | Etd_1202                | pin         | cemetery | shaft          |                                   | 9.65 Cu-Sn |          |
| 199 Ro.09/Etd.30       | Etd_1203                | pin         | cemetery | shaft          |                                   | 11.9 Cu-Sn |          |
| 200 Ro.09/Etd.31       | Etd_1204                | torque      | cemetery | shaft, this has Ca |                                   | 14.9 Cu |          |
| 201 Ro.09/Etd.32       | Etd_1205                | pin         | cemetery | shaft          |                                   | 10.9 Cu-Sn |          |
| 202 Ro.09/Etd.33       | Etd_1206_1              | pin         | cemetery | shaft          |                                   | total 45.75 Cu-Sn |          |
| 203 Ro.09/Etd.33       | Etd_1206_2              | torque      | cemetery | body           |                                   | total 45.75 Cu-Sn-Pb |          |
| 204 Ro.09/Etd.34       | Etd_1207                | pin         | cemetery | shaft          |                                   | 11.9 Cu-Sn |          |
| 205 Ro.09/Etd.35       | Etd_1208                | dagger      | cemetery | body           |                                   | 10.65 Cu-As |          |
| 206 Ro.09/Etd.36       | Etd_1209                | pin         | cemetery | shaft          |                                   | 10.75 Cu-As |          |
| 207 Ro.09/Etd.38       | Etd_1211                | ring        | cemetery | shaft          |                                   | 1.15 Cu-As |          |
| 208 Ro.09/Etd.39       | Etd_1212                | pin         | cemetery | shaft          |                                   | 3.15 Cu-As-Sn |          |
| 209 Ro.09/Etd.40       | Etd_1213                | pin         | cemetery | shaft          |                                   | 4.0 Cu-As-Sn |          |
| 210 Ro.09/Etd.41       | Etd_1214                | needle      | cemetery | shaft          |                                   | 2.6 Cu-As |          |
| 211 Ro.09/Etd.42       | Etd_1215                | needle      | cemetery | shaft          |                                   | 1.7 Cu-As |          |
| 212 Ro.09/Etd.43       | Etd_1216                | bead        | cemetery | shaft          | disc                              | 1.25 Cu-As-Sn |          |
| 213 Ro.09/Etd.45       | Etd_1218                | pin         | cemetery | shaft          |                                   | 10.05 Cu-Sn |          |
| 214 Ro.09/Etd.46       | Etd_1219                | needle      | cemetery | shaft          |                                   | 1.9 Cu-Sn |          |
| 215 Ro.09/Etd.63       | Etd_1235                | dagger      | cemetery | blade          |                                   | 48.75 Cu-As-Sn |          |
| 216 Ro.09/Etd.64       | Etd_1236                | cup         | cemetery | body           |                                   | 31.0 Cu-Sn |          |
| 217 Ro.09/Etd.65       | Etd_1237                | cup         | cemetery | body           |                                   | nm Cu-Sn |          |
| 218 Ro.09/Etd.66       | Etd_1238                | pin         | cemetery | shaft          |                                   | 7.3 Cu-Sn |          |
| 219 Ro.06/M138         | Etd_13                  | pin         | cemetery | shaft          |                                   | 32.30 Cu-Sn |          |

(Continued)
| Obj. Excavation number | Museum Inventory number | Object type | Context | Analysis point | Typology (where applicable)/Notes | Weigh | Alloy type |
|------------------------|-------------------------|-------------|---------|----------------|----------------------------------|-------|------------|
| 220 Ro.06/M138         | Etd_14                  | pin         | cemetery shaft |                |                                  | 26.2  | Cu-Sn      |
| 221 Ro.06/M138         | Etd_15                  | pin         | cemetery shaft |                |                                  | 9.35  | Cu-Sn      |
| 222 Ro.06/M38          | Etd_16                  | bead        | cemetery body | disc           |                                  | 9.75  | Cu-Sn      |
| 223 Ro.06/M140         | Etd_17                  | pin         | cemetery shaft |                |                                  | 9.0   | Cu-Sn      |
| 224 Ro.06/M140         | Etd_18                  | pin         | cemetery shaft | head           |                                  | 14.0  | Cu-As-Sn   |
| 225 Ro.06/M120         | Etd_2                   | pin         | cemetery head  |                |                                  | 10.45 | Cu-Sn      |
| 226 Ro.06/M142         | Etd_20                  | torque      | cemetery body |                |                                  | 36.35 | Cu-Sn      |
| 227 nd Etd_2003_1     | cup                     | cemetery body | fragment     | nm; partially oxidized | Cu-As |               |
| 228 nd Etd_2003_11    | pin                     | cemetery shaft |              | nm; partially oxidized | Cu-Sn |               |
| 229 nd Etd_2003_12    | pin                     | cemetery shaft |              | nm; partially oxidized | Cu-Sn |               |
| 230 nd Etd_2003_14    | pin                     | cemetery shaft |              | nm; partially oxidized | Cu-Sn-Pb |               |
| 231 nd Etd_2003_2     | pin                     | cemetery shaft |              | nm; partially oxidized | Cu-Sn |               |
| 232 nd Etd_2003_4     | pin                     | cemetery shaft |              | nm; partially oxidized | Cu-As |               |
| 233 nd Etd_2003_5     | cup                     | cemetery body | fragment     | nm; partially oxidized | Cu-Sn |               |
| 234 nd Etd_2003_6     | pin                     | cemetery shaft |              | nm; partially oxidized | Cu-Sn |               |
| 235 nd Etd_2003_7     | pin                     | cemetery shaft |              | nm; partially oxidized | Cu-Sn |               |
| 236 nd Etd_2003_8     | pin                     | cemetery shaft |              | nm; partially oxidized | Cu-Sn |               |
| 237 Ro.06/M124        | Etd_21                  | ring        | cemetery body |                |                                  | 4.1   | Cu-Sn      |
| 238 Ro.06/M143        | Etd_23                  | pin         | cemetery shaft |                |                                  | 14.25 | Cu-Sn      |
| 239 nd Etd_24         | pin                     | cemetery head |              |                |                                  | 38.5  | Cu-Sn      |
| 240 Ro.06/M143        | Etd_25                  | pin         | cemetery head  |                |                                  | 16.0  | Cu-Sn-Sb   |
| 241 Ro.06/M144        | Etd_26                  | pin         | cemetery head  |                |                                  | 5.4   | Cu-As      |
| 242 nd Etd_27         | bead                    | cemetery     | fragment     | nm              |                                  | 52.75 | Cu-As-Ag-Au|
| 243 Ro.06/M145        | Etd_28                  | pin         | cemetery head  |                |                                  | 7.9   | Cu-Sn      |
| 244 Ro.06/M145        | Etd_29                  | pin         | cemetery head  |                |                                  | 21.6  | Cu-Sn      |
| 245 Ro.06/M120        | Etd_3                   | pin         | cemetery head  |                |                                  | 5.5   | Cu-Sn      |
| 246 Ro.06/M147        | Etd_31                  | pin         | cemetery shaft |                |                                  | 9.0   | Cu-Sn      |
| 247 Ro.06/M147        | Etd_32                  | cup         | cemetery body | fragment     |                                  | 52.75 | Cu-As      |
| 248 nd Etd_35         | bead                    | cemetery body | tubular      | not measured   |                                  | 101.8 | Cu-Sn      |
| 249 Ro.06/M154        | Etd_37                  | axe         | cemetery blade |                |                                  | 18.3  | Cu-Sn      |
| 250 Ro.06/M126        | Etd_4                   | pin         | cemetery shaft | vase-headed |                                  | 17.85 | Cu-As      |
| 251 M126 Etd_41      | cup                     | cemetery body | fragment     |                |                                  | 16.7  | Cu-Sn      |
| 252 Ro.06/M126        | Etd_5                   | pin         | cemetery head | vase-headed |                                  | 16.7  | Cu-As      |
| 253 Ro.06/M121        | Etd_6                   | pin         | cemetery shaft |                |                                  | 16.75 | Cu-As-Sn   |
| 254 Ro.06/M129, Etd_7 | Etd_1041                | pin         | cemetery shaft |                |                                  | 14.25 | Cu-Sn      |
| 255 Ro.06/M129, Etd_9 | Etd_1043                | pin         | cemetery shaft |                |                                  | 3.4   | Cu-As      |
| 256 Ro.04/Etd.2       | Etd_980                 | hair ring   | cemetery body |                |                                  | 2.15  | Cu-Ag      |
| 257 Ro.04/Etd.3       | Etd_981                 | pin         | cemetery shaft |                |                                  | 11.15 | Cu-Sn      |
| 258 Ro.04/Etd.4       | Etd_982                 | pin         | cemetery shaft |                |                                  | 2.45  | Cu-As      |
| 259 Ro.04/Etd.5       | Etd_983                 | ring        | cemetery body |                |                                  | 19.1  | Cu-Sn      |
| 260 Ro.04/Etd.6       | Etd_984                 | axe         | cemetery blade |                |                                  | 34.63 | Cu-As      |
| 261 Ro.04/Etd.7       | Etd_985                 | pin         | cemetery shaft |                |                                  | 7.3   | Cu-Sn      |
| 262 Ro.04/Etd.8       | Etd_968                 | pin         | cemetery head, shaft |          |                                  | 11.6  | Cu-As      |
| 263 Ro.04/Etd.10      | Etd_968                 | pin         | cemetery shaft |                |                                  | 2.45  | Cu-Sn      |

(Continued)
Table 2. (Continued)

| Obj. Excavation number | Museum Inventory number | Object type | Context          | Analysis point | Typology (where applicable)/Notes | Weigh | Alloy type |
|------------------------|-------------------------|-------------|------------------|----------------|-----------------------------------|-------|------------|
| 264 Ro.04/Etd.11       | Etd_989                 | pin         | cemetery         | head, shaft    |                                   | 20.45 | Cu-Sn      |
| 265 Ro.04/Etd.12       | Etd_990                 | earring     | cemetery         | gold leaf coating | lead core coated with Au         | 1.75  | Cu-Au      |
| 266 Ro.04/Etd.13       | Etd_991                 | pin         | cemetery         | shaft          |                                   | 1.65  | Cu-As-Sn   |
| 267 Ro.04/Etd.14       | Etd_992                 | cup         | cemetery         | body           |                                   | 29.25 | Cu-Sn      |
| 268 Ro.04/Etd.15       | Etd_993                 | pin         | cemetery         | shaft          |                                   | 49.3  | Cu-Sn      |
| 269 Ro.04/Etd.16       | Etd_994                 | bracelet    | cemetery         | body           |                                   | 20.5  | Cu-Sn      |
| 270 Ro.04/Etd.17       | Etd_995                 | pin         | cemetery         | shaft          |                                   | 25.03 | Cu-Sn      |
| 271 Ro.04/Etd.18       | Etd_996                 | pin         | cemetery         | shaft          |                                   | 22.8  | Cu-Sn      |
| 272 Ro.04/Etd.20       | Etd_998                 | torque      | cemetery         | body           |                                   | 32.8  | Cu-Sn      |
| 273 Ro.04/Etd.21       | Etd_999                 | cup         | cemetery         | body           |                                   | 69.0  | Cu-Sn      |
| 274 M28                 | nd                      | cup         | cemetery         | body           | lead cup                          | >300.0| Pb         |
| 275 Mo.04_M70          | nd                      | ring        | cemetery         | body           |                                   | nm    | Cu         |
| 276 Mo.04_M80          | nd                      | ring        | cemetery         | body           |                                   | 2.1   | Cu-Sn      |
| 277 Mo.04_M82          | nd                      | bead        | cemetery         | disc           |                                   | 0.55  | Cu-Ag      |
| 278 Ro06_19_M140       | nd                      | bracelet    | cemetery         | body           |                                   | 49.65 | Cu-As      |
| 279 Ro.11_8            | 9104                    | pin         | cemetery         | head           |                                   | nm    | Cu         |
| 280 Ro.11_8            | 9104                    | pin         | cemetery         | shaft          |                                   | nm    | Cu-Sb      |
| 281 Ro.11_10           | 9106                    | pin         | cemetery         | head           |                                   | nm    | Cu         |
| 282 Ro.11_10           | 9106                    | pin         | cemetery         | shaft          |                                   | nm    | Cu-Ar      |
| 283 nd                 | Etd_1243                | pin         | cemetery         | head           |                                   | nm    | Cu-Sb      |
| 284 nd                 | Etd_1243                | pin         | cemetery         | shaft          |                                   | nm    | Cu-Ar      |
| 285 nd                 | Etd_1244                | pin         | cemetery         | head, shaft    |                                   | nm    | Cu-Sb      |
| 286 Ro.15_22           | 9651                    | axe         | settlement       | blade          |                                   | nm    | Cu-As      |
| 287 Ro.10_6            | Etd_1248                | pin         | cemetery         | head           |                                   | nm    | Cu-Sb      |
| 288 Ro.10_6            | Etd_1248                | pin         | cemetery         | shaft          |                                   | nm    | Cu         |
| 289 Ro.10_1            | Etd_1260                | pin         | cemetery         | head           |                                   | nm    | Cu-As      |
| 290 Ro.10_1            | Etd_1260                | pin         | cemetery         | shaft          |                                   | nm    | Cu-As-Sb   |
| 291 Ro.10_2            | Etd_1261                | pin         | cemetery         | head, shaft    |                                   | nm    | Cu-As      |
| 292 Ro.11_8            | Etd_1276                | pin         | settlement       | head, shaft    |                                   | nm    | Cu-Sb      |
| 293 Ro.11_22           | Etd_1290                | pin         | settlement       | head, shaft    |                                   | nm    | Cu         |
| 294 Ro.11_28           | Etd_1303                | pin         | settlement       | head, shaft    |                                   | nm    | Cu         |
| 295 Ro.11_29           | Etd_1304                | pin         | settlement       | head, shaft    |                                   | nm    | Cu-As      |
| 296 Ro.11_30           | Etd_1305_1              | earring     | cemetery         | head           |                                   | nm    | Cu         |
| 297 Ro.11_30           | Etd_1305_1              | earring     | cemetery         | shaft          |                                   | nm    | Cu-Sb      |
| 298 Ro.11_30           | Etd_1305_2              | earring     | cemetery         | head           |                                   | nm    | Cu         |
| 299 Ro.11_30           | Etd_1305_2              | earring     | cemetery         | shaft          |                                   | nm    | Cu-Sn-Sb   |
| 300 Ro.11_31           | Etd_1306_1              | bead        | cemetery         | body           |                                   | nm    | Cu         |
| 301 Ro.11_31           | Etd_1306_2              | bead        | cemetery         | body           |                                   | nm    | Cu         |
| 302 Ro.11_31           | Etd_1306_3              | pendant     | cemetery         | body           |                                   | nm    | Cu         |
| 303 Ro.11_31           | Etd_1306_4              | pendant     | cemetery         | body           |                                   | nm    | Cu-Sn      |
| 304 Ro.12/7            | Etd_1320                | drill?      | settlement       | body           | with wooden handle                | nm    | Cu-As      |
| 305 Ro.12/8            | Etd_1356                | drill?      | settlement       | body           |                                   | nm    | Cu         |
| 306 Ro.12/72           | Etd_1357                | chisel      | settlement       | body           |                                   | nm    | Cu-As      |
| 307 Ro.12/81           | Etd_1362                | pin         | settlement       | head, shaft    |                                   | nm    | Cu         |

https://doi.org/10.1371/journal.pone.0269189.t002
terms of both time and cost. This method is beneficial for museum-housed objects in countries like Turkey where permits are restricted and controlled, and tight regulations exist regarding the movement of artifacts. The analyses of the Resuloğlu artifacts were conducted between 2016 and 2018 in the Çorum Museum. The rules and regulations of the Turkish Ministry of Culture and Tourism were followed precisely during museum studies. This included but was not limited to a restriction on sampling from complete pieces or conducting surface cleaning on certain objects, especially on precious metals like gold.

While pXRF is an effective way for non-invasive analyses of museum artifacts, it has undeniable handicaps [e.g., 50–52]. It is a surface-analysis technique and can be used to analyze only to a depth of approximately 0.05mm, depending on the target element and matrix of the artifact. The technique cannot, therefore, provide bulk compositions for the objects. Confirmation of the bulk analysis or metallurgy of the artifacts through destructive methods or metallography was not possible, due to limitations in the allocation of museum-based research permits. The surface analysis might also read elevated values of tin due to surface segregation. To minimize this problem, all surfaces were mechanically cleaned in the Çorum Museum.

A total of 307 objects with appropriate surface conditions were analyzed by using a portable Bruker Tracer SD-IV pXRF spectrometer. Analyses were conducted on a stand to minimize any instability caused by the vibration of the instrument. Out of the 400 metals and metal fragments, only 307 were analyzed. Almost 25% of the complete collection was not analyzed due to severe corrosion.

The X-ray tube type used was a rhodium target. 40kV and 15.80μA were selected under air (non-vacuum), with a titanium-aluminum filter of 25μ titanium in layer 1 and 300μ aluminum in layer 2. This is the automatic filter specification of the instrument in filter number one and is the standard setting of the instrument used for metal analysis. The instrument was calibrated according to copper alloy standards BCR 691 A, C, D, and BAM 211. The analysis time was adjusted to 180 seconds. Each reading was repeated three times to obtain an average. The majority of the artifacts were analyzed at least from two different spots.

Chemical compositions are treated as decisive for alloy types. Elemental composition of greater than 1 wt% is accepted as an alloy (bronze, arsenical copper, etc.). Lead is an exception for which the limit is set as 5 wt%. These limits are used here in concordance with similar studies [e.g., 5, 6, 53], hence allowing us to present a common ground for comparisons. All percentages referred here are given wt%. The average of the compositional results with analysis points is provided in S1 Table. This methodology follows similar studies from the region [6, 53].

**Lead Isotope Analysis (LIA)**

The use of lead isotope analysis allows researchers to discover from which ore sources the copper in an artifact has been derived [54, 55]. This helps to reconstruct certain trade and exchange networks, thus indicating socio-economic linkages. In this study, 42 samples were taken from 40 different specimens. Samples with compositional results were prioritized for isotopic analysis. However, 12 samples lack pXRF results due to the level of surface corrosion.

The lead isotope ratios measured on the Resuloğlu metals were then compared with the extensive database of ores compiled from the literature [e.g., 56–62]. The data was then correlated with samples from the Delive Valley Survey (hereafter DVS) project conducted in the region between 2016–2018 by a team of archaeologists, geologists, and geomorphologists (Fig 7). The DVS focused specifically on ore sampling at the eastern zone of the Delive River for two reasons: 1) the proximity of these sources to Resuloğlu, and 2) to complement the isotopic data already available for the northern Anatolian ore deposits [56]. Seeliger et al.’s [56]
research focusing on the north Anatolian ores together with excavations at Derekutuğun cover the western part of the river where the Derekutuğun copper deposits are located [62].

Yalçın and İpek [62] have argued Derekutuğun as the ultimate copper source for the 3rd millennium BC settlements in north-central Anatolia and beyond. Their technological deterministic approach is based on the fact that early societies were using Derekutuğun due to its massive capacity, easy availability, and closeness to ancient settlements. While there is no doubt about the rich reserves of Derekutuğun, their argument does not discuss cultural choices and priorities, thus is inadequate to explain the socio-economic systems of past societies. Consequently, the DVS prioritized the understudied small sources around the region to expand the data and to test the hypothesis of whether Derekutuğun has been the source of copper to all Resuloglu copper-based metals. Accordingly, five native copper and malachite samples from Killik Tepe, Öksen Deresi, Bakırçay, and Üçoluk Deresi at the Karaevliya village were sampled to expand the available lead isotope dataset (S2 and S3 Figs).

Lead isotope ratio analyses were carried out at the Middle East Technical University Radio-isotope Laboratory using a Thermo-Fischer Triton TI TIMS in static multi-collection mode. The procedure, published in Batmaz et al. [63: p. 408–411], was followed with slight changes. All weighing, chemical dissolution, and chromatographic procedures were carried
out using ultrapure water and chemicals in the Class 100 cleanroom. Each sample weighed approximately 100 mg and was transferred to high-purity PFA (perfluoroalkoxy copolymer resin) vials. The samples were completely dissolved in 4 ml 14 HNO$_3$ on a 160°C hotplate for two days. After being dried on a hotplate, the samples were dissolved in 4 ml of 6N HNO$_3$ for one day. They were then evaporated on a hotplate before being dissolved again in 1 ml 2N HCl.

The lead was separated from the dissolved archaeological metal using Bio-Rad AG1-X8, 100–200 mesh anion-exchange resin in 1 ml columns. A total of 2 M HCl and 0.8 M HBr were used during the chromatographic filtration, and then lead was collected using 6M HCl. The sample was loaded on re-filaments using silica gel and 0.005 N H$_3$PO$_4$, and measured in static mode between 1200–1350°C. Analytical uncertainties were given at 2-sigma. The measurement accuracy was controlled with frequent measurements of the NIST SRM 981 lead wire standard reference material alternating with the course of the sample measurements. The NIST SRM 981 standard was measured as 16.938, 15.493, and 36.708 (n = 10) for $^{206}$Pb/$^{204}$Pb, $^{207}$Pb/$^{204}$Pb, and $^{208}$Pb/$^{204}$Pb respectively. By using NBS values, necessary corrections were made. The analytical accuracy was consistently around or less than 0.1%, which is sufficient for the determination of provenance [61, 64]. The $^{206}$Pb/$^{204}$Pb, $^{207}$Pb/$^{204}$Pb, $^{208}$Pb/$^{204}$Pb, $^{206}$Pb/$^{206}$Pb, $^{208}$Pb/$^{206}$Pb, and $^{208}$Pb/$^{207}$Pb ratios and standard errors for Resuloglu metal samples and five new ore deposits are listed in S2 Table.

Results

pXRF analysis

pXRF analysis allows us to expose surface compositional analysis and to have a basic understanding of questions related to alloying choices. Nonetheless, in archaeometallurgical research, it is hard to draw a line between intentional and unintentional alloying. Relevant literature presents variable distinctions between the deliberate and accidental use of alloys [65: p. 114–115; 66: p. 62]. For this study, an elemental composition greater than 1 wt% is accepted as an alloy except for lead whose limit is set as 5 wt%. These limits used are in concordance with similar studies [6, 53], hence allowing us to present a common ground for comparisons. All the percentages presented in this study are weight percentages. The artifacts are referred to using the museum inventory numbers as stated in Table 2 and S1 Table.

The total of 307 objects from 18 different artifact types shows an unanticipated variety for the use of metals in the Resuloglu assemblage. Eighteen different alloying practices along with the use of unalloyed copper, silver, and lead are identified (Fig 6). Bronze identified on 161 objects constitutes the most common alloy type. This is followed by arsenical copper alloy documented on 56 objects. Unalloyed copper is the third major group recognized in 29 artifacts. Unalloyed lead and silver are represented by one artifact each. The ternary alloy of Cu-As-Sn is detected on 15 pieces. The other alloying practices documented are Cu-Ag (8), Cu-Sb (7), Cu-Ag-Au (6), Cu-Sn-Pb (4), Cu-As-Ag-Au (4), Cu-Sn-Sb (2), Cu-As-Ag (2), Au-Ag-As (2), Cu-Au (1), Cu-As-Au (1), Cu-Ag-Au-Sb (1), Au-As (1), and Au-Ag (1) (Fig 8).

A statistically reliable relation is not confirmed between object type and alloy type (Fig 9). Still, certain artifact types favor particular alloys. For example, 28 out of 40 of the beads are made of bronze. Similarly, pins, anklets, torques, and bracelets also favor bronze, but examples made of other alloys were identified. Anklets are made of either bronze (4) or Cu-Sn-Pb (1) alloys. While the majority of the bracelets are made of bronze, unalloyed copper (3), arsenical copper (1), and Cu-As-Sn (2) examples were also identified. The only chisel (Etd_1357) of the assemblage is arsenical copper containing 97.57% copper and 1.5% arsenic. The only metal seal was found in the settlement and is arsenical copper with 9.25% arsenic.
Fig 8. Distribution of metal and alloy types in the analyzed metal corpus of Resuloğlu.

https://doi.org/10.1371/journal.pone.0269189.g008
Sixteen cups examined in the assemblage display five different compositions: Cu-Ag (1), Cu-Pb (1), arsenical copper (3), bronze (10), and lead (1). The Cu-Ag cup (7902) weighs 42 gr and consists of 65.7% copper and 25.37% silver. The Cu-Pb cup fragment (Etd_1006) contains 93.6% copper and 5.65% lead and weighs 17.85 gr. The only unalloyed lead artifact is also a cup from a burial context (M28) containing 94.7% lead. Drills are made of unalloyed copper (1) and arsenical copper (2). Needles are either made of copper alloyed with arsenic (3) or tin (2).

Among the implements, six of the eight axes are arsenical copper. The remaining two are bronze. Daggers were manufactured from bronze (3), arsenical copper (2), and Cu-As-Sn (1). The only knife (Etd_1140) analyzed in the assemblage is bronze with 9.39% tin. The only mace head found at Resuloğlu (7901) weighs 178.95 gr and contains 98.94% copper with trace amounts of arsenic and antimony.

Various alloys include gold but no pure gold objects were detected. An earring (8625) made of stone is coated with a thin leaf of Au-Ag alloy containing 95.36% gold and 3.47% silver. A lead earring (Etd_990) is coated similarly with a golden-colored leaf, which is determined as a Cu-Au alloy of 3.91% copper and 85.92% gold. The 2.52% lead detected on the object must be due to the core (Fig 10).
One earring (Etd_1194) contains 2.09% arsenic and 94.23% gold. The ternary alloy of Au-Ag-As is determined in two beads (7908_1, 7908_3). These swastika-shaped beads contain similar percentages of gold (93.23% and 93.35%), silver (1.47% and 1.4%), and arsenic (1.25% and 1.46%) (S3 Fig). Cu-Ag-Au and Cu-As-Ag-Au alloys are identified on beads and earrings. An earring (8614_1) containing 27.3% copper, 51.96% silver, 16.6% gold, and 4.22% antimony makes the object unique not only for Resuloğlu but also for the regional contemporaneous assemblages [6].

The only silver object is a ring (Etd_1151_1) containing 41.51% silver. The total weight percentage of the object is below one hundred due to chlorine ions of the silver oxidation, which cannot be measured via pXRF. The only hair ring (Etd_980) in the collection is made of Cu-Ag with 61.68% copper and 21.61% silver. Cu-As-Ag alloy is detected on a ring (Etd_1083) and a torque (7701).

Antimonial copper objects, dated as early as the 4th millennium BC, are known from the region [6]. In Resuloğlu antimony-bearing alloys include antimonial copper (bead, earring, pin), Cu-Sn-Sb (earring and pin), Cu-Ag-Au-Sb (earring), and Cu-As-Sb (earring and pin). Only one bead (Etd_1096_3) has been found as antimonial copper. This suggests a preference for antimony-bearing alloys for the production of pins and earrings.

The variety in the alloy types of the cemetery is not noticeable in the settlement. There are only 12 metal artifacts found in the settlement: a seal, a few pins, an axe (9651), a chisel (Etd_1357), and two drills (Etd_1320, Etd_1356). The most common alloy in domestic contexts is arsenical copper (axe, seal, chisel, and pins) followed by unalloyed copper. The only antimonial copper pin (Etd_1276) is from the settlement. The metal consumption at the settlement is not dense. The assemblage of the settlement mostly consists of utilitarian objects; the
object types and alloys are not as diverse as in the cemetery. The only metal seal from the site was recovered at the settlement on the floor of a silo. No seals were found in the cemetery.

Bronze appears as the most common alloy in Resuloğlu. Bronze objects seem to be reserved for burials and not recovered from the domestic contexts. This demonstrates the intentional consumption of tin-bearing objects as burial goods. If tin-containing artifacts had been used at the settlement, they must have been removed and/or recycled during or after the settlement’s lifetime [e.g., 52].

While all tin-bearing alloys are accumulated at the cemetery, the settlement’s metal corpus relies on arsenical and unalloyed copper. The polymetallic sources containing copper, arsenic, and antimony were available within proximity to Resuloğlu (i.e., 10–100km) [6]. The availability and accessibility of minor deposits, most of which are unknown to modern scholars due to a lack of systematic surveys and data accusation, should have sufficed for small communities like Resuloğlu to exploit [67]. Besides, the patchy distribution of minor metallic deposits must have been difficult to control for any ruling group.

The 3rd millennium BC north-central Anatolian sites offer a partial answer to whether the local settlers exploited local metal sources. There is not enough regional, well-stratified data to settle this. Nonetheless, it would be logical to argue that villages in the region periodically sent groups to mine and smelt ores for extensive seasonal mining [68: p. 137].

Tin is not locally available. The closest known tin sources to the region are in the Taurus Mountains and at Hisarcık [42–44]. This suggests that the reserved consumption of rare metals must have arrived at Resuloğlu via an exchange system. This argument applies also to gold and silver objects and their alloys, which have also been encountered only in the burial contexts.

The pXRF results demonstrate the difference in metal consumption between the settlement and the cemetery. The majority of the metals were left as burial gifts, whereas stone tools and implements appear commonly in use in the settlement. The low number of metal objects from the settlement supports this situation in the domestic areas. All of the metal objects at the settlement were found in regular houses, whereas the village-head’s residence did not yield any metals. This indicates that at Resuloğlu, the use of metal tools, the existence of bronze items, or the ownership of metals were not prime markers of the leading segments.

Metallographic examinations were not possible at Resuloğlu due to permit limitations. Thus, it is not plausible to contribute to metal production and working techniques. Additionally, no archaeological context relevant to metal production was uncovered at the site. Accordingly, our data validate that the settlers of the site had fairly good access to various types of metal items made of different alloy types. The lead isotope results support this suggestion.

**Lead isotope analysis**

Lead isotope ratios are a frequently applied method to determine the possible ore sources of metal artifacts. The positive matches in lead isotope ratios indicate the source from which the metal could have come [69, with references]. Isotopic studies have been conducted to a lesser extent in Turkey due to the limitations of excavation and research budgets. Regarding this, the sample set presented in this study constitutes of a unique set to evaluate the flow of metals during the 3rd millennium BC in north-central Anatolia.

The classification of metal goods as local or as an import has led the way to different scenarios for trade networks expanding from Mesopotamia to central Anatolia. For north-central Anatolia, the majority of scholars privilege local Hatti metalworking and metal schools [e.g., 24, 30, 47, 70]. According to such technologically deterministic models, the local Hattian craftspeople of north-central Anatolia were exploiting and processing the available sources such as the Pontides. These skilled local metalsmiths have been pointed out as the producers of
the metal caches, yet the literature has a limited discussion of metallurgical production and activity zones. This is partially due to the continuous occupation of the region and the continuous exploitation of its metallic sources, as well as the high density of forestation near the Black Sea coast, which has hindered archaeological excavations and surveys.

The occurrence of mineral deposits in north-central Anatolia is far too numerous to even catalog here. While the metallic sources in the region are rich, it should not always be concluded that they were used as available sources. Behavioral and societal parameters such as choices of past communities might shape the use of proximate sources in a way that might not be driven purely by technology or function. Additionally, the archaeological evidence regarding the ultimate use of nearby sources is thin. However, metal assemblages of middle-range societies in north-central Anatolia have not been systematically sampled and analyzed to propose a new model that explains metal production and flow. Resuloğlu’s metal corpus is unique in that it provides the biggest lead isotope data from a single site.

The lead isotope results were compared to data on available ore from the Caucasus, Iran, Cyprus, and Anatolia. Immediately apparent in the data set are the two separate groups of objects superimposed with the Anatolian ore sources. Thus, the Caucasus, Iran, and Cyprus data are eliminated from the following figures and discussion. Fig 11 presents $^{207}\text{Pb}/^{206}\text{Pb}$ versus $^{208}\text{Pb}/^{206}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ groupings for Resuloğlu metals compared with published ore

![Fig 11. Lead isotope ratio binary graphs displaying $^{207}\text{Pb}/^{206}\text{Pb}$ vs. $^{208}\text{Pb}/^{206}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ of analyzed Resuloğlu metal samples compared to the published ore data from the Tauride and Pontide, and central Anatolia.](https://doi.org/10.1371/journal.pone.0269189.g011)
data from the Tauride and Pontide, and central Anatolia. Fig 12 demonstrates $^{206}\text{Pb}/^{204}\text{Pb}$ versus $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ graphs. In both diagrams, the lead isotope ratios of Resuloğlu metals cluster at the Tauride and Pontide ores in almost equal numbers.

The lead isotope data is further grouped into six by using P. de Jesus’ model [24, 71], which broadly draws copper exploitation zones in prehistoric Anatolia based on certain artifact typologies and copper sources. De Jesus grouped the copper exploitation zones in prehistoric Anatolia into six plausible production zones: 1) Kûre group refers to ores from Kastamonu, i.e., western Black Sea coast; 2) Yapraklı group includes sources from Ankara, Çankırı, Çorum, Amasya, and Yozgat area, i.e., central Black Sea and north-central Anatolian zone; 3) Pontic group involves ores of the Sivas and Tokat region; 4) Giresun-Trabzon group refers to the area spanning Ordu, Trabzon, and Gümüşhane; 5) Murgul-Kuvarshan group involves the western edge of the polymetallic sources of Erzurum, Kars, and Artvın. i.e., eastern Black Sea coast; and 6) Ergani group refers to the metallic ores of the Elazığ-Diyarbakır area. This zoning is particularly useful when site and resource distributions are concerned. Additionally, it presents a basic sense of resource accumulation. However, the borders of each zone should be considered hypothetical.

This study builds on this classification by also adding the Taurus Mountain range into the discussion. According to the lead isotope results, Bolkardağ-Aladağ-Nigde massif in the central
Taurus range appears as a plausible provenance for a significant number of the samples. Table 3 lists the possible provenance of the metal objects from Resuloğlu as source groups and specifics of resource locations such as Ankara ores as part of the Yapraklı group or Bolkardağ-Aladağ as part of the central Taurus zone.

| Lab_code | Museum_No | Alloy type | Object Type | Source (Groups) | Specifics of the Source |
|----------|------------|------------|-------------|------------------|-------------------------|
| 23913_01_Pb | M28 | Pb | lead cup | Yapraklı | Ankara |
| 23913_02_Pb | Etd 1016 | nd | pin | Kure | Kastamonu |
| 23913_03_Pb | Etd 14 | nd | pin | Yapraklı | Amasya |
| 23913_04_Pb | Etd 1109 | nd | pin | Central Taurus | Aladağ |
| 23913_05_Pb | Etd 1002 | Cu-As | pin | Pontic | Sivas |
| 23913_06_Pb | Etd 1112 | Cu-Sn | dagger | Yapraklı | Ankara |
| 23913_07_Pb | Etd 1100 | Cu-Sn | cup | Central Taurus | Aladağ |
| 23913_08_Pb | Etd 1143 | Cu-Sn | cup | Central Taurus | Bolkardag |
| 23913_09_Pb | Etd 1237 | Cu-Sn | cup | Central Taurus | Aladağ |
| 23913_10_Pb | Etd 1195 | Cu-As-Ag-Au | earring | Pontic | Sivas |
| 23913_11_Pb | Etd 1206 | Cu-Sn-Pb | torque | Central Taurus | Aladağ |
| 23913_12_Pb | Etd 1238 | Cu-Sn | pin | Central Taurus | Aladağ |
| 23913_13_Pb | Etd 999 | Cu-Sn | cup | Pontic | Yozgat |
| 23913_14_Pb | M70 | Cu | pin | Central Taurus | Aladağ |
| 23913_15_Pb | Etd 982 | Cu-As | pin | Central Taurus | Aladağ |
| 23913_16_Pb | 2003/11 | Cu-Sn | cup | Central Taurus | Aladağ |
| 23913_17_Pb | 2003/4 | Cu-As | earring | Yapraklı | Ankara |
| 23913_18_Pb | 2003/1 | Cu-As | cup | Pontic | Sivas_Tokat, Öksen |
| 23913_19_Pb | Etd 992 | Cu-Sn | cup | Central Taurus | Bolkardag |
| 23913_19_Pb (2) | Etd 992 | Cu-Sn | cup | Central Taurus | Bolkardag |
| 23913_20_Pb | Etd 1017 | Cu-Sn | torque | Central Taurus | Bolkardag |
| 23913_20_Pb (2) | Etd 1017 | Cu-Sn | torque | Central Taurus | Bolkardag |
| 23913_21_Pb | Etd 1031 | Cu-As | dagger | Kure | Kastamonu |
| 23913_22_Pb | Etd 1025 | Cu-Sn | torque | Central Taurus | Bolkardag |
| 23913_23_Pb | Etd 39 | Cu-As | pin | Yapraklı | Ankara |
| 23913_24_Pb | Etd 998 | Cu-Sn | torque | Pontic | Sivas |
| 23913_25_Pb | 2005/5 | Cu-Sn | bead | Central Taurus | Bolkardag |
| 23913_26_Pb | 2003/13, M30 | nd | bead | Yapraklı | Ankara |
| 23913_27_Pb | 2003/13, M26 | nd | bead | Yapraklı | Amasya |
| 23913_28_Pb | Etd 38 | nd | pin | Central Taurus | Aladağ |
| 23913_29_Pb | Etd 1041 | Cu | pin | Central Taurus | Bolkardag |
| 23913_30_Pb | 2003/08, M9 | Cu-Sn | pin | Yapraklı | Ankara (Uçoluk) |
| 23913_31_Pb | 2003/10, M28 | Cu-As | pin | Yapraklı | Ankara (Uçoluk) |
| 23913_32_Pb | 2003/09, M26 | nd | pin | Central Taurus | Bolkardag |
| 23913_33_Pb | Etd 1014 | nd | pin | Yapraklı | Ankara/Amasya |
| 23913_34_Pb | Etd 1024 | nd | bead | Yapraklı | Uçoluk |
| 23913_35_Pb | Etd 16 | Cu-Sn | bead | Pontic | Sivas |
| 23913_36_Pb | Etd 4 | Cu-Sn | pin | Central Taurus | Aladağ |
| 23913_37_Pb | Etd 37 | Cu-Sn | axe | Central Taurus | Aladağ |
| 23913_38_Pb | Etd 32 | Cu-As | cup | Pontic | Sivas_Tokat, Öksen |
| 23913_39_Pb | Etd 1011 | Cu-Ag | ring | Central Taurus | Aladağ |
| 23913_40_Pb | Etd 1022 | Cu-Sn | cup | Central Taurus | Bolkardag |

https://doi.org/10.1371/journal.pone.0269189.t003
The lead isotope analysis results display a diverse use and complex pattern of metal consumption. Accordingly, Resuloglu has not only accessed metals from its proximate sources, but its trade network expanded towards the southern fringe of the Halys Basin as far as the Taurus Mountains. This presents for the first time a scenario contrary to the previously suggested models of metal production and consumption in north-central Anatolia.

The isotope ratios of Resuloglu’s metals match the sources from both the north and the south. Out of 42, 22 samples cluster with the central Tauride ores, namely in the Bolkardag and Aladağ regions. The remaining 20 samples relate to the Yaprakli, Pontic, and Kure groups. Among the northern sources, 11 samples relate to the Yaprakli group, specifically Ankara, Amasya, and Corum Uçoluk. Seven metal samples demonstrate Pontic provenance, mostly to Sivas. The Kure group (Kastamonu) is the possible provenance of a pin (Etd_1016) and a dagger (Etd_1031). Giresun-Trabzon, Murgul-Kuvarshan, or Ergani groups are not likely provenances for any objects. This signals that Resuloglu’s exchange and trade network did not expand to the eastern part of the Black Sea coast.

The isotopically analyzed metals constitute less than a quarter of the whole metal collection. Nonetheless, the results disprove the suggestion that the 3rd millennium BC communities of north-central Anatolia have been benefiting solely from local or proximate sources. Resuloglu displays an almost equal distribution of metals sourced from both northern and southern sources. Especially for metals provenanced to the central Taurus, a direct or an indirect supply chain must have existed. Resuloglu’s chief might have controlled to a degree the supply and accumulation of metals. The settlers of the site must have been part of this supply chain by providing grain and possibly textiles.

Suggesting a definite relation between alloy type, object type, and provenance is not easy at Resuloglu (Figs 13 and 14). For example, the provenances of different arsenical copper objects match those of Yaprakli, Pontic, Kure, and the central Taurus. Two unalloyed pins (M70, Etd_1041) and a Cu-Ag ring (Etd_1011) point to the central Taurus as a possible provenance. A Cu-As-Ag-Au earring (Etd_1195) matches the Pontic group (Sivas). Thus, a comparison at this stage is not possible. The only unalloyed lead object of the Resuloglu collection, cup M28, falls into the Yaprakli group. The lead isotope ratios of this lead cup match well with the jasmonite (PbFeSbS14) sample from Kizilcahamam, Ankara.

Bronze objects show Yaprakli (2), Pontic (3), and the central Taurus (14) as likely provenances. The number of bronze finds originating from the Bolkardağ and Aladağ zones constitutes approximately 73.4% of the isotopically analyzed samples (Fig 14). While the existence of tin in the Yaprakli and Pontic regions is unclear, tin is present at the Niğde massif (Bolkardağ) of the central Taurus range [72]. For the exploitation of tin during the 3rd millennium BC at the Niğde massif, a multi-tier production model composed of a mining site (Kestel) and its associated specialized mining settlement (Göltepe) was suggested [42, 43, 73].

Lead isotope ratios for the majority of bronze objects from Resuloglu coincide with the isotopic ratios of Bolkardağ and Aladağ. This supports an operating production zone during the 3rd millennium BC in the central Taurus, for which Kestel-Göltepe appears the most plausible candidate. Some typological similarities between the metals of Resuloglu and Göltepe are intriguing to note. For example, the majority of the bronze torques from Resuloglu is provenanced to the central Taurus, where a typological counterpart made out of silver was documented at Göltepe [42: pl.27, M23; 43: p. 206, Fig 23]. The provenance of a Cu-Sn-Pb torque (Etd_1206) from Resuloglu also falls into the central Taurus group, specifically in the Aladağ zone.

The central Tauride isotopic signatures match well with most of the torques and cups among the Resuloglu metals. Similar objects with a Pontic ore signature are also available at Resuloglu. The beads are clustered with Ankara, Amasya, and Uçoluk sources. One bronze...
bead (Etd_16) falls into Pontic-Sivas cluster while the other (2005/5) aligns well with Bolkardağ ratios. The isotope ratios of the pins align with all four groups.

There are eight axes in the Resuloğlu metal collection, only one of which could be sampled. The lead isotope ratios of this bronze axe (Etd_37) correspond to Aladağ. One of the arsenical copper daggers (Etd 1031) originates from Küré-Kastamonu, whereas the copper of the bronze example (Etd 1112) is more likely to come from the Yapraklı ores, specifically from Ankara. The typologies of both daggers were already identified with the northern styles [30, 74]. This archaeological suggestion is now confirmed with analytical data.

To sum up, any relationship between the object type and the potential source does not exist. For example, there is no evidence to confidently argue that all torques from Resuloğlu originated from the central Taurus or that all pins are from Küré or Yapraklı. This shows that some potential resource areas could not be equated with specialized workshops to produce certain types of metal items. There is decentralization in production and consumption.

**Discussion**

The compositional results of the Resuloğlu metals demonstrate significant diversity in metal and alloy consumption in the late 3rd millennium BC north-central Anatolia. While pXRF does not provide information about the bulk compositions of the artifacts, the method...
successfully presents variety in metal composition. Various binary and ternary alloys of copper were identified among which bronze is the most common. Alloys of copper with silver and gold were revealed. It is hard to draw a line between intentional and unintentional alloying at Resuloğlu, but natural alloys might be deliberately used [cf. 6, 75].

The 3rd millennium BC Anatolian metallurgy has been so far oversimplified to unalloyed copper, arsenical copper, and bronze through interpreting the evidence via normative modes of consumption. This appears as overgeneralizing the data from small, subjectively selected metals, failing to notice diversity. The compositional results of a broad corpus from a single site present such an assortment for the first time.

The lead isotope ratios provide detailed implications of metal transactions at Resuloğlu. The results define a flow of metals to the site from two major locales: 1) relatively proximate sources such as Yapraklı, Küre, and Pontic, among which Yapraklı is the closest network, and 2) macro-regional exchange outside the Halys Basin, i.e., the central Taurus region. This

![Fig 14. Numerical distribution graphs of alloy types and object types among suggested provenance (source groups) of metal objects.](https://doi.org/10.1371/journal.pone.0269189.g014)
macro-regional metal flow exposes that the 3rd millennium BC societies of north-central Anatolia have indeed imported metals despite being in proximity to deposits. These metals were possibly exchanged in finished forms because any semi-finished fragment or assemblage associated with metalworking such as molds, tuyeres, crucibles, or slags has not been uncovered at the site or in its vicinity. The metal artifacts uncovered in both domestic and burial contexts confirm that the settlers of Resuloğlu were consumers of metal products rather than being producers of them.

The consumer side of the metal flow has been mostly overlooked in Anatolian archaeology [cf. 76: p. 145; 77: 88–89]. Among the metals at Resuloğlu, the most common items are overwhelmingly personal ornaments such as pins and beads; tools are rare. Any regalia like those found in contemporary Alaca Höyük, Horoztepe, Eskiyapar, or Mahmatlar are absent. This signals that the primary consumer demand at Resuloğlu was personal ornamentation, and secondarily for implements. There is no noticeable demand for items related to political or religious ceremonies [cf. 2: p.124].

At Resuloğlu, the archaeological and analytical data demonstrate an excellent case for metal consumption in a middle-range society, where evidence about the existence of elites is absent. Thus, Resuloğlu’s metal artifacts are better identified with valuables [78] than prestige goods [1].

The accumulation of wealth in terms of metals in burial contexts is not a marker of social inequality [79: p.250]. At Resulوغlu, differential wealth is notable with diverse numbers of burial gifts including ceramics, semi-precious stones, faience, or shell; however, a large number of metal objects was not found in a single grave. While this study did not cover the full context of the burials due to a forthcoming publication focusing on the cemetery, 20 years of excavations and studies demonstrate that the archaeological and anthropological data will hardly render a visibly and tangibly stratified community.

According to Hayden [80], wealth accumulation in subsistence economies favors more useful, storable food stocks rather than rare goods. This argument resonates at Resulوغlu, where grain silos had served as food supplies. Valuables like metals, faience, or carnelian have a role in a non-domestic context. Compared to the other 3rd millennium BC sites in the region where social inequality is more apparent from burial goods and practices like Alaca Höyük, we argue that social inequality resonates in different pathways within the same region. There have to be changing relationships of social position, wealth, control, and ritual roles within north-central Anatolian communities [cf. 79: p.234]. On a regional scale, different communities must have been interacting with each other for economic advantage [2].

Resulوغlu did not yield any remains related to metal production. Thus, any discussions at this stage about the context of production based on metals found in a burial context will be misleading. Focusing on the nonstate exchange systems is promising to explore the consumer side of metal economics at Resulوغlu. The diversity in metal compositions and types at Resulوغlu indicates metal acquisition without elite control in the Halys Basin. Nonelite-controlled metal trade is not unique to Anatolia but also documented in various parts of the world like China, Thailand, Spain, and among Asian pastoralist groups [81].

Nonstate economies generally have a variety of exchange and trade systems due to their incorporation into nonmarket economies. In less stratified, middle-range societies like Resulوغlu, reciprocal exchange is one of the pillars of the economic system [82]. At Resulوغlu, a give-and-take system established in alliance networks would have worked not only for valuables but also for basic stuff like ceramics or textiles. The ceramic corpus of the site is local to the Halys Basin, therefore confirming intracommunity exchange. While some products leave little trace in the archaeological record disproportionate to their economic role [2: p.118], the exchange of clothing and other basic organic and inorganic products such as textiles and salt
should be encountered within this economic system. Resuloğlu’s metal network extended to the north and the south within Anatolia; however, a direct linkage to the Syro-Mesopotamia was not detected isotopically. Even though some typological similarities such as the Ur type bead (Etd_1156) [30] have been established with Mesopotamia, these must be Anatolian-made copies of imports.

The north-central Anatolian communities have been long identified as part of the Hatti culture that dominated the Halys Basin in the 3rd millennium BC. The region’s metal corpus has also been linked to local and skilled Hattian craftspeople. Hitherto, Resuloğlu as a small, self-sustaining, middle-range society demonstrates compositionally and provenancially a diverse metal collection. The consumption patterns of metals at Resuloğlu do not resonate with technologically deterministic models. The functionally or religio-political display of metals does not seem the case at the site. The existence of bronze objects in most of the burials signifies that elites were not necessary for the consumption of certain metals or valuables.

Conclusions

This study presents analytical and archaeological information on the metal assemblage of Resuloğlu, which is spatially and temporally the largest fully provenanced and analyzed archaeological sample set from the 3rd millennium BC north-central Anatolia. The comprehensive assessment of the metal collection in its archaeological context with a well-established chronology strengthens the significance of the study. The interdisciplinary approach demonstrates variability over the dimensions of metal and alloy use, typology, and context.

White and Hamilton [81] argue that cherry-picked samples employed in most of the regional ancient metallurgy research overlook important elements of metal collections, thus resulting in prejudiced conclusions regarding the role of metal in ancient societies. This statement is true for archaeometallurgy research in Anatolia, whereby bronze, elites, and long-distance trade have been disproportionately discussed for decades over the possible variable place of metals in everyday society. Trade and control over surplus are important for the emergence of social inequality but not always the reason [79: p. 251].

Agriculture and, to a certain extent, textile production represent the pillars of Resuloğlu’s subsistence economy. Two decades of excavation have yielded no metal production-related archaeological context or remains. The settlers of the site appear as consumers of metal products. Considering the accumulation of metals at the Resuloğlu cemetery, the flow of such commodities and exchange/trade networks should be examined to comprehend the sphere of interaction and socio-economic relations of the site. We argue that there is an intracommunity exchange in the region, for which Resuloğlu provided grain and textiles and in return metal items. The compositional and isotopic analyses support such networks and economic relationships. Additionally, comparing Resuloğlu with contemporaneous sites supports the fact that the metal consumption in all of the 3rd millennium BC communities is not equal.

Resuloğlu presents a high degree of variability in metal types and alloys indicative of community-driven choices and networks that were not under the control of social elites or any top-down political system. The evidence supports a picture of decentralized production and distribution of goods shaped around local preferences. Resuloğlu maintained this system—probably with some adjustments yet unknown—during its lifespan of 400 years.

Archaeological sites in different cultural and environmental settings necessitate new, bottom-up models to comprehensively uncover the role of metals in economics [2, 81, 83]. Developing appropriate fresh models for understanding the 3rd millennium BC Anatolian metallurgy require not only new excavations and archaeometric analysis, i.e., data, but also a new theoretical framework. Resuloğlu as a middle-range society presents clear evidence of
nonstate, decentralized consumption of functionally and technologically diverse metal products. We argue that heterarchical local and regional exchange networks operated here. This opens a new discussion in the bronze age metallurgy of Anatolia to rethink models favoring elite-controlled production and consumption of metals.

The concept of middle-range societies is not novel to world archaeology but is here proposed for the first time for the 3rd millennium BC north-central Anatolian communities. We believe that Resuloğlu’s data display an excellent case to push forward the shift from top-down perspectives to community-choice-driven models. Hopefully, future studies in the region explore, test, and develop our arguments to assess the role of metals in the socioeconomics of ancient Anatolia.

Supporting information

S1 Table. pXRF analysis on the Resuloğlu metal assemblage. The inventory numbers with an asterisk (*) designate artifacts with lead isotope analysis results.

S2 Table. Lead isotope ratios of Resuloğlu metal objects and copper ores collected from the DVS area. Objects with an asterisk (*) also have a pXRF analysis.

S1 Fig. Native copper samples collected from the Bakırçay region during the Delice Valley Survey (image ©Dardeniz).

S2 Fig. Copper ore samples collected from the Bakırdere region during the Delice Valley Survey (image ©Dardeniz).

S3 Fig. Swastika-shaped beads (7908_1, 7908_3) made of gold-silver-arsenic alloy (image ©Resuloğlu excavations archive).

Acknowledgments

The authors are indebted to the Turkish Ministry of Culture and Tourism and the Çorum Museum for providing the necessary permits to excavate and conduct research at Resuloğlu. Ankara University, Istanbul Technical University, and Istanbul University support the archaeological and scientific research at the site. We thank the Koç University Department of Archaeology and History of Art for providing us with the pXRF equipment. We thank Serhat Koksal from Middle East Technical University for running the lead isotope analysis. We are particularly grateful to all the members of the Resuloğlu excavation team for their hard work over the many years. We extend our gratitude to Deniz Yazıcı for helping out with the maps created in QGIS. The statistical evaluations and the graphs are prepared by using the software JMP SW 14. This paper benefited tremendously from the valuable and constructive comments of three anonymous reviewers. We thank them for their contribution to this paper.

Responsibility for any mistakes and inaccuracies must be assigned to the authors.

Author Contributions

Conceptualization: Gonca Dardeniz.

Data curation: Gonca Dardeniz, Tayfun Yıldırım.
Formal analysis: Gonca Dardeniz.
Funding acquisition: Gonca Dardeniz, Tayfun Yıldırım.
Investigation: Gonca Dardeniz, Tayfun Yıldırım.
Methodology: Gonca Dardeniz.
Project administration: Gonca Dardeniz.
Resources: Gonca Dardeniz, Tayfun Yıldırım.
Software: Gonca Dardeniz.
Supervision: Gonca Dardeniz, Tayfun Yıldırım.
Validation: Gonca Dardeniz, Tayfun Yıldırım.
Visualization: Gonca Dardeniz, Tayfun Yıldırım.
Writing – original draft: Gonca Dardeniz.
Writing – review & editing: Gonca Dardeniz, Tayfun Yıldırım.

References
1. Earle T. The evolution of chiefdoms. In: Earle T. editor. Chiefdoms: Power, economy and ideology. Cambridge (UK): Cambridge University Press; 1991. pp. 1–15.
2. White JC, Hamilton EG, (editors). Ban Chiang, Northeast Thailand, volume 2A: Background to the study of the metal remains. Philadelphia: University of Pennsylvania Press; 2018.
3. Yağcı Ü. Ancient metallurgy in Anatolia. In: Yağcı Ü, Özbal H, Paşamehmetoğlu AG. editors. Ancient mining in Turkey and the eastern Mediterranean. Ankara: Atatürk University; 2000. pp. 15–40.
4. Massa M, Palmisano A. Change and continuity in the long-distance exchange networks between western/central Anatolia, northern Levant and northern Mesopotamia, c. 3200–1600 BCE. Journal of Anthropological Archaeology. 2018; 49: 65–87. https://doi.org/10.1016/j.ja.a.2017.12.003
5. Dardeniz G, Yıldırım T. Resulolu (Çorum, Turkey) updated: preliminary results of pXRF analysis of metal artifacts from the early bronze age cemetery. In: Kulakolu F, Michel C, Öztürk G. editors. SUB ARTU, Külepe International Meeting 3. Turnhout, Belgium: Brepols; 2020. pp. 141–161.
6. Dardeniz G. Why did the use of antimony-bearing alloys in bronze age Anatolia fall dormant after the early bronze age?: A case from Resulolu (Çorum, Turkey). PLoS ONE 15(7), e0234563. 2020. Available from: https://doi.org/10.1371/journal.pone.0234563 PMID: 32673336
7. Seeher J. Die Bronzezeitliche Nekropole von Demirchöyük-Sariket, Ausgrabungen des Deutschen Archäologischen Instituts in Zusammenarbeit mit dem Museum Bursa 1990–1991, Istanbuler Forschungen Band 44. Tübingen: Ernst Wasmuth Verlag; 2000.
8. Zimmermann T. Kalinkay-Toptaştepe, eine chalkolithisch-frühbronzezeitliche Siedlung mit Nekropole im nördlichen Zentralanatolien: Die Grabfunde der Kampagnen von 1971 und 1973. Istanbuler Mitteilungen. 2007; 57: 7–26.
9. Koşar HZ. Ausgrabungen von Alaca Höyük, 1936. Ankara: Türk Tarih Kurumu Basımevi; 1944.
10. Koşar HZ. Alaca Höyük Kazısı 1937–1939’daki çalışmalar ve keşiflere ait ilk rapor. Ankara: Türk Tarih Kurumu Basımevi; 1951.
11. Koşar HZ, Akok M. Türk Tarih Kurumu tarafından yapılan Alaca Höyük kazısı 1940–1948’deki çalışmalar ve keşiflere ait ilk rapor: Ausgrabungen von Alaca Höyük Vorberichtüber die Forschungen und Entdeckungen von 1940–1948. Ankara: Türk Tarih Kurumu Basımevi; 1966.
12. Koşar HZ, Akok M. Türk Tarih Kurumu tarafından yapılan Alaca Höyük Kazısı 1963–1967 çalışmalar ve keşiflere ait ilk rapor/Alaca Höyük excavations: Preliminary report on research and discoveries 1963–1967. Ankara: Türk Tarih Kurumu Basımevi; 1973.
13. Bachhuber C. Citadel and cemetery in early bronze age Anatolia (Monographs in Ancient Mediterranean Archaeology 58). Sheffield: Equinox; 2015.
14. Harding AF. European societies in the Bronze Age. Cambridge: Cambridge University Press; 2000.
15. Harding AF. World systems, cores, and peripheries in prehistoric Europe. European Journal of Archaeology. 2013; 16 (3): 378–400. https://doi.org/10.1017/S1461957113Y.000000002
16. Kristiansen K, Earle T. Neolithic versus bronze age social transformations, a political economy approach. In: Kristiansen K, Šmejda L, Turek J, editors. Paradigm found: Archaeological theory-present, past and future. Essays in honour of Evžen Neustupný. Oxford: Oxbow Books; 2014. pp. 236–249.

17. Feinman GM, The emergence of inequality: a focus on strategies and processes. In: Price TD, Feinman GM, editors. Foundations of social inequality, fundamental issues in archaeology. New York: Plenum Press; 1995. pp. 255–280.

18. Rousseau J. Hereditary stratification in middle-range societies. Journal of the Royal Anthropological Institute. 2001; 7(1): 117–131. https://doi.org/10.1111/1467-9655.00053

19. Kienlin T. Some thoughts on evolutionist notions in the study of early metallurgy. In: Bartelheim M, Horne J. Hereditary stratification in middle-range societies. Journal of the Royal Anthropological Institute. 2001; 7(1): 117–131. https://doi.org/10.1111/1467-9655.00053

20. Kienlin T, Zimmermann A. (eds.), Beyond elites. Alternatives to hierarchical systems in modelling social formations. Bonn: Verlag Dr. Rudolf Habelt GMBH; 2012.

21. Stork L. Systems of value and the changing perception of metal commodities ca. 4000–2600 BC. Journal of Near Eastern Studies. 2015; 74 (1): 115–132. https://doi.org/10.1086/679651

22. Bachhuber C. Negotiating metal and the metal form in the royal tombs of Alacahöyük in north-central Anatolia. In: Wilkinson TC, Sherratt S, Bennet J, editors. Interweaving worlds: Systemic interactions in Eurasia 7th to 1st millennia BC. Oxford: Oxbow Books; 2011. pp. 158–174.

23. Wengrow D. ‘Archival’ and ‘sacrificial’ economies in bronze age Eurasia: an interactionist approach to the hoarding of metals. In: Wilkinson TC, Sherratt S, Bennet J, editors. Interweaving worlds: Systemic interactions in Eurasia 7th to 1st millennia BC. Oxford: Oxbow Books; 2011. pp. 135–144.

24. De Jesus P. The development of prehistoric mining and metallurgy in Anatolia. BAR International Series 74; 1980.

25. Yalçın Ü, Yalçın G. Königse, Priester oder Handwerker? Neues über die frühbronzezeitlichen Fürstengräber von Alacahöyük. In: Yalçın Ü, editor. Anatolian Metal VIII. Eliten—Handwerk—Prestigegüter, Der Anschnitt Beihetf 39. Bochum: Deutsches Bergbau Museum; 2018. pp: 91–122.

26. Pearson R. Debating Jomon social complexity. Asian Perspectives. 2007; 46 (2), 361–388.

27. Rousseau J. Rethinking social evolution: The perspective from middle-range societies. Montreal: McGill-Queen’s University Press; 2006.

28. Feinman GM, Neitzel J. Too many types: an overview of sedentary prestate societies in the Americas. In: Schiffer MB, editor. Advances in archaeological method and theory vol. 7. New York: Academic Press; 1984. pp. 39–102.

29. Arıkan B, Yıldırım T. Paleoclimate, geology, geomorphology, and middle Holocene settlement systems in the Delice Valley of north-central Anatolia. Journal of Field Archaeology. 2018; 43 (8): 570–590. https://doi.org/10.1080/00934690.2018.1535161

30. Yıldırım T. Yeni araştırmalarla işığında Kuzey Anadolu’da erken Tunc Çağında sanat ve çevre kültürleri ilişkileri. In: Şahoglu V, Şeketolu M, Erbil YH, editors. Connecting Cultures: Trade and Interconnections in the Ancient Near East from the Beginning until the End of the Roman Period, Anatolia Supplement Series I:4. Ankara: 2019. pp. 147–163.

31. Yıldırım T, Kısa A, Çorum / Resuloluğ 2014 yılı kazıları. Çorum Kazı ve Araştırmalar Sempozyumu. 2015; 5: 97–104.

32. Ünar A, Orta Anadolu’da erken Tunc Çağında tahil depolamanın işığında ekonomik ve siyasi örgütlenme, PhD. Dissertation. İzmir: Ege University; 2020.

33. Yıldırım T. An early bronze age cemetery at Resuloluğ, near Uğurұlduk, Çorum, a preliminary report of the archaeological work carried out between years 2003–2005. Anatolia Antiqua. 2006; 14: 1–14. https://doi.org/10.3406/anata.2006.1061

34. Dardeniz G, Yıldırım T, Yıldırım C, Çiftçi E. Blue, green, and white faience bead production techniques in the early bronze age central Anatolian site of Resuloluğ (Turkey), Archaeometry. 2021; 63 (2): 327–342. https://doi.org/10.1111/arch.12606

35. Clarke JE, Blake M. The power of prestige: competitive generosity and the emergence of rank societies in lowland Mesoamerica. In: Brumfiel EM, Fox JW, editors. Factional competition and political development in the new world. Cambridge: Cambridge University Press; 1994. pp. 17–30.

36. Amarasinghe UA, Shah T, Singh OP. Changing consumption patterns: implications on food and water demand in India. IWMI Research Reports 44517, International Water Management Institute. 2007 [cited 2021 September 15]. https://doi.org/10.22004/ag.econ.44517

37. Hillman G. Agricultural productivity and past population potential at Asvan. Anatolian Studies. 1973; 23: 225–240. https://doi.org/10.2307/3642542
38. Earle T. Bronze age economics: the beginnings of political economies. Boulder (CO): Westview Press; 2002.
39. Yıldırım T. Resulolu kazısı ve Anadolu arkeolojisine katkıları. Çorum Kazi ve Araştırmalar Sempozyumu. 2011; 1: 11–28.
40. Randsborg K. Rank, rights and resources—An archaeological perspective from Denmark. In: Renfrew C, Shennan S, editors. Ranking, resource, and exchange. Cambridge: Cambridge University Press, 1982. pp. 132–139.
41. Radijovič M, Roberts BW, Pernicka E, Stos-Gale Z, Martínón-Torres M, Rehren T, et al., The provenance, use, and circulation of metals in the European bronze age: The state of debate. Journal of Archaeological Research. 2019; 27: 131–185. https://doi.org/10.1007/s10814-018-9123-9
42. Yener KA. Göltepe excavations tin production at an early bronze age mining town in the central Taurus Mountains, Turkey. Philadelphia, Pennsylvania: INSTAP Academic Press; 2021.
43. Yener KA. Domestication of metals: The rise of complex metal industries in Anatolia. Leiden: Brill; 2000.
44. Yener KA, Kulakoğlu F, Yazgan E, Kontani R, Hayakawa YS, Lehner JW, et al. New tin mines and production sites near Kültepe in Turkey: A third-millennium bc highland production model. Antiquity. 2015; 89, 596–612. https://doi.org/10.15184/aqy.2015.30
45. Powell W, Johnson M, Pulak C, Yener KA, Mathur R, Bankoff HA, et al. From peaks to ports: Insights into tin provenance, production, and distribution from adapted applications of lead isotopic analysis of the Uluburun tin ingots. Journal of Archaeological Science. 2021; 134: 105455. Available from: https://doi.org/10.1016/j.jas.2021.105455
46. Yakar J. Regional and local schools of metalwork in early bronze age Anatolia: Part I. Anatolian Studies. 1984; 34: 59–86. https://doi.org/10.2307/3642858
47. Yakar J. Regional and local schools of metalwork in early bronze age Anatolia: Part II. Anatolian Studies. 1985; 35: 25–38. https://doi.org/10.2307/3642869
48. Costin CL. Thinking about production: phenomenological classification and lexical semantics. In: Hruby ZX, Flad RK, editors. Rethinking craft specialization in complex societies: Archaeological analyses of the social meaning of production. Arlington (VA): American Anthropological Association; 2007. pp. 143–162.
49. Flad R. Rethinking the context of production through an archaeological study of ancient salt production in the Sichuan Basin, China. In: Hruby ZX, Flad RK, editors. Rethinking craft specialization in complex societies: Archaeological analyses of the social meaning of production. Arlington (VA): American Anthropological Association; 2007. pp. 108–128.
50. Pearce M., The Curse of the pXRF: The negative consequences of the popularity of handheld XRF analysis of copper-based metal artefacts. Metalla. 2019; 24 (2): 81–85.
51. Liritzis I, Zacharias N. Portable XRF of archaeological artefacts: Current research, potentials and limitations. In: Shackley MS, editor. X-Ray fluorescence spectrometry (XRF) in geoarchaeology. New York: Springer; 2011. pp. 109–141.
52. Emmitt J, McAlister A, Armstrong J. Pitfalls and possibilities of patinated bronze: The analysis of pre-Roman Italian armour using pXRF. Minerals. 2021; 11 (7), 697. https://doi.org/10.3390/min11070697
53. Lehner JW, Yazgan E, Pernicka E, Kulakoğlu F. Continuity of tin bronze consumption during the late 3rd millennium BC at Kültepe. In: Kulakoğlu F, Michel C, editors. Proceedings of the 1st Kültepe International Meeting. Leuven: Subartu, Brepols; 2015. pp. 195–217.
54. Pryce TO. A flux that binds? The southeast Asian lead isotope project. In: Jett P, McCarthy B, Douglas JG, editors. Scientific research on ancient Asian metallurgy: Proceedings of fifth Forbes symposium at the Freer Gallery of Art. Washington (DC): Archetype Publications, London, and the Freer Gallery of Art, Smithsonian Institution; 2012. pp. 113–121.
55. Pryce TO, Baron S, Bellina BHM, Bellwood PS, Chang N, Chattopadhyay P, et al. More questions than answers: the southeast Asian lead isotope project 2009–2012. Journal of Archaeological Science. 2014; 42: 273–294. http://dx.doi.org/10.1016/j.jas.2013.08.024
56. Seeligcr TC, Pernicka E, Wagner GA, Begemann F, Schmitt-Strecker S, Eibner C, Öztunali Ö, Baranyi I. Archäometallurgische Untersuchungen in Nord und Ostanatolien, Jahrbuch des Römisch-Germanischen Zentralmuseums. 1985; 32: 597–659.
57. Yener KA, Sayre EV, Joel EC, Özbal H, Barnes IL, Brill RH. Stable lead isotope studies of central Taurus ore sources and related artifacts from eastern Mediterranean chalcolithic bronze age sites. Journal of Archaeological Science. 1991; 18: 541–577. https://doi.org/10.1016/0305-4403(91)90053-R
58. Gale NH, Stos-Gale ZA, Maliois G, Annets N. Lead isotope data from the isotope laboratory, Oxford: Archaeometry data base 4: Ores from Cyprus. Archaeometry. 1997; 39: 237–246. https://doi.org/10.1111/j.1475-4754.1997.tb00802.x
59. Sayre EV, Joel EC, Blackman MJ, Yener KA, Özbal H. Stable lead isotope studies of Black Sea Anatolian ore sources and related bronze age and Phrygian artefacts from nearby archaeological sites. Appendix: New Central Taurus ore data. Archaeometry. 2001; 43: 77–115. https://doi.org/10.1111/1475-4754.00006

60. Wagner GA, Wagner I, Öztunalı Ö, Schmitt-Strecker S, Bergemann F. Archaemetallogischer Bericht über Feldforschung in Anatolien und Bleisotopische Studien an Erzen und Schlacken. In: Stöllner T, Körlin G, Steffens G, Cierny J, editors. Man and mining—Mensch und Bergbau. Bochum: Deutsches Bergbau-Museum; 2003. pp. 475–494.

61. Stos-Gale ZA, Gale NH. Metal provenancing using isotopes and the Oxford archaeological lead isotope database (OXALID). Archaeological and Anthropological Sciences. 2009; 1: 195–213. https://doi.org/10.1007/s12520-009-0011-6

62. Yalçın Ü, İpek Ö, (editors). Prähistorische Kupfergewinnung in Derekkütûn, Anatolien, Band I: Montanarchäologische Forschungen in den Jahren 2009–2011, Ein Vorbericht, Der Anschnitt Beiheft 30. Bochum: Deutsches Bergbau Museum; 2016.

63. Batmaz A, Lehner JW, Dardeniz G. Long-distance interaction in Urartu?: Provenance and composition of copper alloys from Ayanis, Turkey. Archaeometry. 2019; 61: 406–422. https://doi.org/10.1111/arcm.12428

64. Gale NH, Stos-Gale Z. Lead isotope analyses applied to provenance studies. In: Ciliberto E, Spoto G, editors. Modern analytical methods in art and archaeology. New York: John Wiley and Sons; 2000. pp. 503–584.

65. Kenoyer JM, Miller HML. Metal technologies of the Indus Valley tradition in Pakistan and western India. In: Pigott V, editor. The archeometallurgy of the Asian old world. MASCA Research Papers in Science and Archaeology Vol. 16., Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology; 1999. pp. 107–151.

66. Stach T. Aspects of early metallurgy in Mesopotamia and Anatolia. In: Pigott V, editor. The archeometallurgy of the Asian old world. MASCA Research Papers in Science and Archaeology Vol. 16., Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology; 1999. pp. 59–71.

67. Killick D. From ores to metals. In: Roberts BW, Thornton PT, editors. Archeometallurgy in global perspective methods and syntheses. New York: Springer; 2014. pp. 11–45.

68. Stöllner T. Methods of mining archaeology (Montanarchäologie). In: Roberts BW, Thornton PT, editors. Archeometallurgy in global perspective methods and syntheses. New York: Springer; 2014. pp. 133–159.

69. Pernicka E. Provenance determination of archaeological metal objects. In: Roberts BW, Thornton PT, editors. Archeometallurgy in global perspective methods and syntheses. New York: Springer; 2014. pp. 239–268.

70. Özgüç T. Early Anatolian archaeology in the light of recent research. Anadolu. 1963; 7: 1–21.

71. De Jesus P. Metal resources in ancient Anatolia. Anatolian Studies. 1978; 28: 97–102. https://doi.org/10.2307/3642745

72. Yener KA, Özbal H. Tin in the Turkish Taurus mountains: The Boğar Kaya mining district. Antiquity. 1987; 61: 220–226. https://doi.org/10.1017/S0003598X00052029

73. Lehner JW, Yener KA. Organization and specialization of early mining and metal technologies in Anatolia. In: Roberts BW, Thornton PT, editors. Archeometallurgy in global perspective methods and syntheses. New York: Springer; 2014. pp. 529–557.

74. Gémez G. L’armement en métal au Proche et Moyen-Orient Des origines à 1750 av. J.-C. PhD dissertation. Paris: Université de Paris I Panthéon-Sorbonne; 2007.

75. Thornton CP. The emergence of complex metallurgy on the Iranian plateau. In: Roberts BW, Thornton CT, editors. Archeometallurgy in global perspective methods and syntheses. New York: Springer; 2014. pp. 665–696.

76. Roberts BW. Ancient technology and archaeological cultures: understanding the earliest metallurgy in Eurasia. In: Roberts BW, Vander Linden M, editors. Investigating archaeological cultures: Material culture, variability, and transmission. New York: Springer; 2011. pp. 137–150.

77. Fowler C. The emergent past: A relational realist archaeology of early Bronze Age mortuary practices. Oxford: Oxford University Press; 2013.

78. Dalton G. Aboriginal economics in stateless societies. In: Earle TK, Ericson JE, editors. Exchange systems in prehistory. New York: Academic Press; 1977. pp. 191–212.

79. Hayden B. Richman, poorman, beggarman, chief: the dynamics of social inequality. In: Feinman GD, Price TD, editors. Archaeology at the millennium: A sourcebook. New York: Kluwer Academic/Plenum; 2001. pp. 231–272.
80. Hayden B. The dynamics of wealth and poverty in the transegalitarian societies of southeast Asia. Antiquity. 2001; 75(289): 571–581. https://doi.org/10.1017/S0003598X00088803

81. White JC, Hamilton EG. The metal age of Thailand and Ricardo’s law of comparative advantage. Archaeological Research in Asia. 2021; 27: 100305. https://doi.org/10.1016/j.ara.2021.100305

82. Cross JR. Craft Specialization in Nonstratified Societies. Research in Economic Anthropology 1993. 14, 61–84.

83. Stech T, Maddin R. Reflections on early metallurgy in southeast Asia. In: Maddin R, editor. The beginning of the use of metals and alloys: Papers from the second international conference on the beginning of the use of metals and alloys, Zhengzhou, China, 21–26 October 1986. Cambridge (MA): MIT Press; 1988. pp. 163–174.