The Production and Perception of Bronze in Mycenaean Greece

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INTRODUCTION

The Aegean Bronze Age, the period in Greek prehistory between 3000 BCE and 1100 BCE (Camp and Fisher 2002:18-19; exact dates vary slightly, but this is a generally accepted time frame), is best characterized by the introduction and utilization of bronze metal.[1] In particular, the alloy tin-bronze is associated with the later part of this period, and especially with the mainland culture of the Mycenaeans. Named so by Heinrich Schliemann, the German man who discovered the archaeological site of Troy, the term 'Mycenaean' has been given to this culture after the settlement at Mycenae in the Argolid region of the Peloponnese.

The discovery and excavation of Mycenae was greatly aided by Schliemann's love for Greek mythology, particularly the epic works of Homer. One of the more well-known characters in the *Iliad* is Agamemnon, the famed king of Mycenae. This period is also known as the "Heroic Age" due to figures such as Agamemnon, Odysseus, and Achilles, and the events of the fabled Trojan War. This notion has built an image of Mycenaean Greece as wrought with war, aided by finds of bronze arrowheads, spearheads, swords, and armor. Additionally, an abundance of gold objects uncovered on the Mycenaean citadel in the 19th century BC has promoted the idea of a wealthy and prosperous society. However, a closer investigation of bronze metallurgy on the mainland seems to indicate otherwise.

The matter of tin-bronze production in Mycenaean Greece is problematic; this is primarily due to the fact that such an industry may not have been in practice by the Mycenaeans at the time. Thus, it is the goal of this paper to evaluate the evidence provided by the archaeological record and in the corpus of Linear B tablets to determine whether or not the Mycenaeans were actively

[1] I would like to dedicate this honors thesis to my parents; without your support, I could not have made it through all of this.

producing tin-bronze. In doing so, certain aspects of Mycenaean society are revealed or further elaborated, such as the socio-economic state of the mainland at the end of the Bronze Age.

The matter of *production* versus *working* must first be addressed in order to establish a distinction in meaning between the two terms. For the purposes of this paper, *production* will refer to the creation of bronze through the technique of alloying. Through this method, new metal is produced, and recycled material is not utilized in the process. Conversely, *working* refers to any metallurgical act performed on bronze that was already alloyed, such as recycled scrap metal or ingots; note that this term may also be applied to a stand-alone metal, such as copper or tin.

Additionally, to better understand the chronological changes in bronze production and working, it is necessary to clarify the terminology that will be used to describe various periods within the Bronze Age. Aegean Bronze Age chronology utilizes relative dating, in which archaeological material is assigned to a category rather than an absolute date. This is accomplished by dividing the Aegean into three main culture areas and time periods. The culture areas are identified as the Minoans on the island Crete, the Cycladic culture of the Cyclades (the island group that falls between Crete and the mainland), and the Helladic culture on the mainland. In addition, each culture area has three major periods: Early, Middle, and Late. These can be combined into pairs to refer to various periods of time within each culture area. For example, EC for Early Cycladic, or MM for Middle Minoan. Furthermore, each period can be subdivided into I, II, and III, which is represented as such: EC I or MM II. There are further subdivisions that will not be discussed, as they are not necessary for the purpose of this paper.

The structure of the paper is as follows: **Chapter 1** provides a basic explanation of the metallurgical processes involved in copper, tin, and bronze metallurgy. This aids in understanding processes, techniques, and terminology that are used freely throughout the rest of the paper. **Chapter 2** addresses where metal resources found in objects across the Aegean might have come from, and the acquisition of such resources. Particular attention is given to tin, as it is the most problematic element in the question of Aegean bronze production. **Chapter 3** thoroughly examines the evidence for bronze metallurgy in the archaeological record from various sites, chiefly the Minaon site at Mochlos and the mainland settlement at Nichoria. Finally, **Chapter 4** explores the implications of etymologies of words pertaining to metal, and how the Linear B corpus may provide further insight to the evidence outlined in the previous chapters.

CHAPTER ONE

An Overview of Bronze Metallurgy

1.1 Introduction

First, it is important to define what is meant by 'bronze'. The term 'bronze' may be used to describe a combination of copper (Cu) with the metals tin (Sn), arsenic (As), lead (Pb), or any configuration of the three (Papadimitriou 2008:271). These combinations are called alloys, which, according to G. Papadimitriou, are "material[s] with metallic properties, homogeneous in macroscopic scale, and consisting of two or more elements, of which one at least is a metal" (Papadimitriou 2008:271). It should be noted that bronze is not equivalent to brass, which is an alloy of copper and zinc (Zn). Brass appears as a yellow-gold metal, which shows some resemblance to highly polished bronze, but occurs less frequently in the archaeological record during this period. Brass is also more malleable than bronze, meaning the metal is softer and changes shape more easily when struck, presumably making brass a less desirable material for tools, weapons, and armor. Regardless of the functionality of either alloy, both bronze and brass contain the all-important ingredient of copper, arguably the most influential metal in early human history.

1.2 Copper

In Aegean Bronze Age chronology, the period which occurs between the Neolithic age of stone tools and the illustrious advent of bronze is known as the Final Neolithic period (FN; 4500-3000 BCE, Halstead and Isaakidou 2013:130). In Near Eastern archaeology, the introduction of bronze occurs in the Chalcolithic period (c. 2700/2800-2400/2500 BCE, Steel 2010:807). The term Chalcolithic is derived from the Greek words *χαλκός* (chalkos), meaning copper or bronze in

Ancient Greek[2], and *λίθος* (lithos), meaning stone; alternatively, this age may sometimes be referred to as the Eneolithic, or Aeneolithic, in which the Latin *aeneus* also denotes either copper or bronze. Although both *χαλκός* and *aeneus* have dual meanings, in this context they are to be understood as 'copper'.[3] While at first the combination of these two terms to describe a period based upon what technology was being utilized may seem counterintuitive, there is sufficient evidence for the simultaneous use of stone and copper tools at this time in the Aegean (Karimali 2008:315). Primarily characterized by the introduction of metalworking to the list of specialized crafts across cultures, the Chalcolithic is a part of the larger Age of Metals (Chalcolithic/Copper Age, Bronze Age, and Iron Age).

Metal occurs as a deposit in the ground, either in a pure, metallic state, or as ore containing a handful of other mineral impurities. The former type of metal formation in regards to copper is called *native copper*. Copper tends to form three types of ores: oxide ores of cuprite (Cu_2O) or tenorite (CuO); sulfide ores of chalconite (Cu_2S) or covellite (CuS); carbonate ores of malachite ($Cu_2(OH)_2CO_3$) or azurite ($Cu_3(OH)_2(Co_3)_2$) (Muhly 1973:171; Penhallurick 1986:4). Since native copper is free of any mineral impurities, it is the simplest to obtain, often found on the surface in the form of nuggets, and is therefore the earliest type of copper (and consequently the earliest metal) to be manipulated by humans (Muhly 1973:171; Jovanović 1980:152).

1.3 Arsenical Copper/Bronze

As previously stated, lead can be incorporated into copper to form bronze. It should be noted, however, that lead is usually added to bronze that already contains some amounts of tin, arsenic, or both. The purpose of alloying lead to bronze is to create an easier pour in the casting

[2] Interestingly, this is characteristic of Ancient Greek only, as Modern Greek uses *ο χαλκός* exclusively for copper and bronze is distinguished as *το μπρούτζο*.
[3] Further discussion of the etymology of these words and their dual meanings can be found in **Chapter 4**.

process, and is normally implemented in the production of finer objects, such as needles or jewelry (Tylecote 1976:29). Lead serves to lower the melting point of the copper alloy, creating a softer, more malleable and ductile metal to work with, which are qualities not well-suited for metal tools or weapons (i.e. objects that are meant to endure a lot of wear and tear in their lifetimes; Tylecote 1976:29, 38). For this reason, such items are predominantly copper alloys of either tin or arsenic.

Arsenic-bronzes, or arsenical coppers, as they are often referred to, are copper alloys with some amount of arsenic, ranging from less than 0.25% to around 12%. However, not all arsenical coppers falling within this scale are considered to be products of human processes; in the case of many deposits of copper, arsenic is a naturally occurring impurity in the ore (Tylecote 1976:8). This means that supposed 'arsenic-bronze' is a natural copper alloy, and in order to differentiate between copper tainted by arsenic and an intentional alloying of the two, it has been proposed that at least 1% of arsenic is sufficient to indicate human interference (Budd and Ottaway 1995:95). Due to its nature as a natural alloy, arsenical copper succeeded the use of native copper alone in metalworking once the technique of *smelting* ore came into practice, as described in greater detail in **§1.5** (Tylecote 1976:14).

1.4 Tin and Tin-Bronze

Tin is by far the most puzzling metal in the equation. Tin-bronze is considered by most as true bronze, and often receives the privilege of simply being called 'bronze', where arsenic-bronze has long ago been demoted to arsenical copper. Yet, very little is known about tin in the Aegean Late Bronze Age (LBA; 1600-1100 BCE; Camp and Fisher 2002:18-19) other than its presence in several bronze artifacts.

Although occurring in both sulfide (stannite)[4] and silicate (malayite) ores, the only tin ore utilized in antiquity appears to have been the oxide cassiterite (SnO_2) (Penhallurick 1986:1; Tylecote 1976:14). The earliest examples of tin-bronze contain only trace amounts of Sn impurities occurring naturally within arsenical copper minerals (Tylecote 1976:15). Copper sources in areas such as Anatolia and the Near East have demonstrated tin contaminants of about 1-3% in addition to varying amounts of arsenic (Tylecote 1976:15; Penhallurick 1986:4); these alloys are commonly referred to as 'low-tin' bronzes. The effects of these impurities upon copper would have made these ores much sought after, as the additives work to increase the hardness and strength of the much more malleable metal.

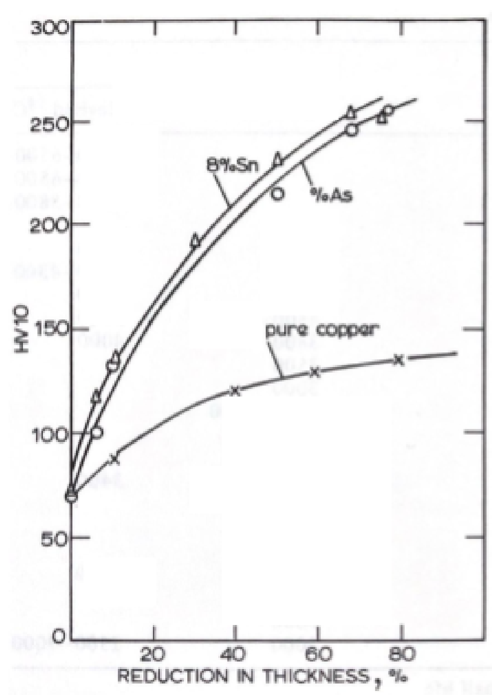

Fig. 1 Hardness effect of tin and arsenic when alloyed with copper after cold hammering; Tylecote 1976:8.

[4] Stannite was not discovered until the 18th century CE in Cornwall, UK; Penhallurick 1986:1.

Once the benefits of these impurities in copper ores were discovered, there was a significant increase in tin (and subsequently a decrease in arsenic) in arsenical coppers. One reason for this shift away from arsenic-heavy metals may be due to the negative health effects attributed to the vapors released when working with this material. It has been suggested that this is a possible origin for the myth of Hephaestos, god of the forge, who is known to have been lame in the foot (Penhallurick 1986:4; Papadimitriou 2008:281). Both tin and arsenic seem to function similarly in improving the strength of copper (Tylecote 1976:15; see **Fig. 1**; the graph shows that tin increases the copper's strength only marginally more than arsenic), so the notion that arsenic saw a decline in use with the introduction of tin to copper due to its toxicity is plausible. This idea is further supported when considering that tin occurs much less frequently in nature, and would have been more difficult to obtain because of geographic constraints, thus providing an explanation for the move away from a much more readily available resource.

1.5 Mining of Metals in Antiquity

Bronze metallurgy ultimately begins with the discovery and mining of copper mineral deposits. Similar to a number of other metalliferous minerals, copper can be found deposited in veins that run through solid rock known as *lodes*. The lodes in which the metal ore forms are then subjected to weathering processes that will cause the mineral to gather into what is called a *placer* or *alluvial* deposit (see **Fig. 2**). These are typically found near rivers and streams, and the collection of copper nuggets in these spots might have been akin to panning for gold in mountain streams during the California Gold Rush (Muhly 1973:248).

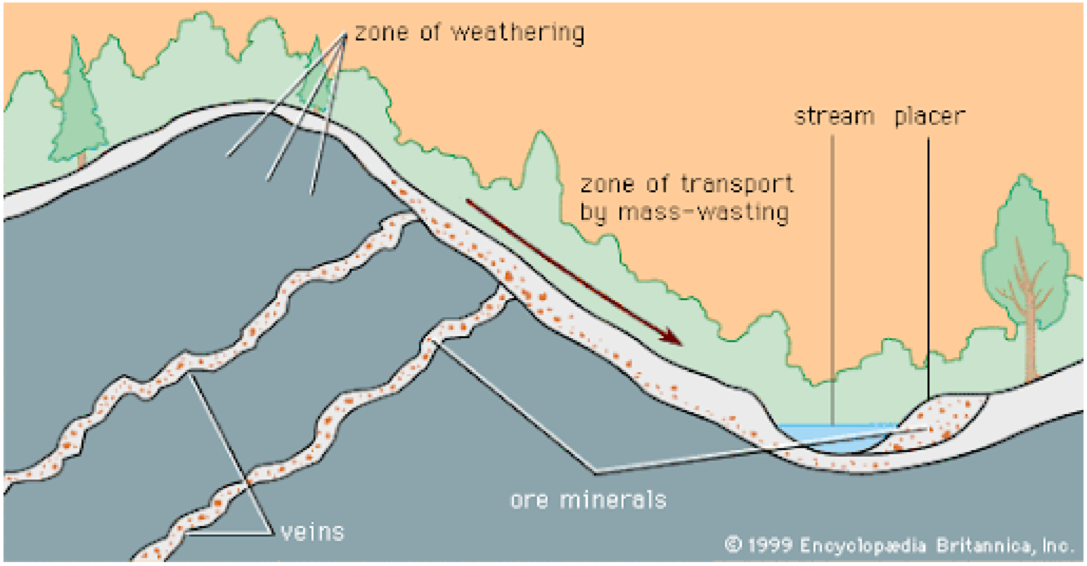

Fig. 2 Diagram of an alluvial or placer deposit.

It becomes slightly more complicated once the source of native nuggets has been depleted, as the next step in the mining process is to extract the copper ore from the rock it is embedded within. Early mines in the Balkans region of Eastern Europe have revealed that this was accomplished by digging open-cast pits, which are more shallow and at the surface level, or with deeper, underground shafts. The desired metal would be extracted through *fire-setting*, a technique in which a fire is set against the ore and then doused with water to create a thermal shock. This will crack the rock enough for the ore to be removed with some form of tool resembling a pickaxe (Penhallurick 1986:58-59, 73-75).

There is significantly less archaeological evidence for the mining of tin, which also forms as veins and placer deposits like copper (Penhallurick 1986:1). However, J. D. Muhly, drawing from the work of R. J. Forbes, seems to be convinced that there was no extractive mining of tin ore before 1500 BCE; rather, that Bronze Age tin acquisition relied upon some kind of panning technique, as previously discussed in regards to native copper (Muhly 1973:248).

In his work *Geography*, ancient Greek geographer and historian Strabo (c. 64/63 BCE to 24 CE) provides an account of how tin was procured in Iberia during his time:

> τὸν δὲ καττίτερον οὐκ ἐπιπολῆς εὑρίσκεσθαί φησιν, ὡς τοὺς ἱστορικοὺς θρυλεῖν, ἀλλ᾽ ὀρύττεσθαι· [...] ἐξανθεῖν φησιν τὴν γῆν ἀργύρῳ, καττιτέρῳ, χρυσῷ λευκῷ (ἀργυρομιγὴς γάρ ἐστι), τὴν δὲ γῆν ταύτην φέρειν τοὺς ποταμούς· τὴν δὲ σκαλίσι τὰς γυναῖκας διαμώσας πλύνειν ἐν ἠθητηρίοις πλεκτοῖς εἰς κίστην.
>
> And [Posidonius] says that tin was not found coming to the surface, as the historians ramble, but was dug; [...] he says that the earth is bursting with silver, tin, white gold (for it is mixed with silver), and this earth is carried by the rivers; and the women harvest it with hoes and wash it in plaited strainers into a basket.[5]
>
> *Strab. 3.2.9*

Immediately of note from this excerpt is Strabo's mention that "tin was not found coming to the surface...but was dug;" This indicates that, in later years, tin mining had shifted to methods of extraction from the rock, when in previous years, it had been "found coming to the surface." Considering Muhly and Forbes' claims, this could reflect a depletion of placer tin deposits at some point between the LBA and the Hellenistic period (323-31 BCE; Camp and Fisher 2002:18-19); this is quite sufficient an amount of time for such an event to be plausible, depending on the scale of the industry in any given stanniferous region.

Strabo goes on to say that "the women harvest [the earth] with hoes and wash it in plaited strainers into a basket." This process bears resemblance to what has been observed in the archaeological record of the early Balkan copper mines, in which the ore is also removed through striking with a pick-axe- or hoe-like tool. Conversely, the method being described could be evidence for the aforementioned river panning of tin nuggets from placer deposits. It is unclear either way if the women with strainers are meant to have washed the extracted ores to remove any

[5] All translations belong to the author of this paper.

dirt before being placed in the baskets for transport, or if these strainers were to sift through the riverbeds for what is, essentially, native tin.

1.6 Ancient Metallurgical Processes

After extraction, the ores must be purified, as they contain other minerals in addition to the desired metal. This is accomplished through a process called *smelting*, in which the ore is heated to its melting point (1084°C for copper, 232°C for tin; Tylecote 1976:15), allowing for any impurities to separate from the molten metal. This was typically done on site or nearby the mine out of convenience (Tylecote 1976:16; Stos-Gale 2004:53). Smelting cannot occur without some form of byproduct, usually as *slag*, which is the stoney, often ferriferous cast-off from the ore, or as gaseous fumes. It must be noted that there are two types of slag: smelting slag, which is the cast-off from the smelting process and what is being addressed above; and crucible slag, which is the byproduct of casting, or moulding (Tylecote 1976:19). Although it is not necessarily difficult to smelt cassiterite into pure tin, experiments led by Daniel Berger attempting to recreate the ancient process of smelting tin have demonstrated that a good portion of tin is lost through these byproducts (Berger, Figueiredo, Brügmann, and Pernicka 2018:77). With so much waste coming out of this ore, it is not difficult to imagine that the remaining amount of pure metal would be coveted; this is another potential agent in the rarity of tin in the ancient Mediterranean world.

Once the ore has been smelted into a usable metallic product, the metal undergoes *alloying*, the combination of a metal with some other component to create a new product with different properties using extreme heat; for our purposes, this is the mixing of copper and tin to create tin-bronze. This could have been accomplished either by pouring together the two melted, pure metals in a crucible, or possibly even by directly smelting the copper and tin ore together (Bass et al. 1967:81; citing Tylecote 1962:28). According to Serge Cleuziou and Thierry Berthoud, the latter method would have produced a bronze with much higher tin content (Cleuziou and Berthoud 1982:15); this is useful to note when considering why certain bronze artefacts may contain tin levels higher than the 10% ideal for ancient tin-bronzes (Rapp, Jones, Cooke, and Henrickson 1978:174; Tylecote 1976:15).

Once the bronze has been alloyed and is molten liquid, it must be *cast* (meaning poured via crucible) into a mould. This mould may mimic the shape of the intended product, such as a spear point, or it could be a simpler geometric shape intended for later use. When it was necessary to ship or store metals to be used elsewhere, the metal would have been cast in a mould that fits the latter category. This product is called an *ingot*, which is a mass of metal, alloyed or not, that is easy to transport and ready to be worked.

From the ingot stage, the metalsmith must either melt the bronze down again to re-cast it into the desired shape, such as a spear point, or hammer the metal as it is. The latter process is called *plastic deformation*, and can be done by one of two methods: *forging*, which is done while the metal is heated; and *hammering*, which is done while the metal is cold (Papadimitriou 2008:273-275). While hammering is more intuitively named than forging, both of these methods involve striking the metal with a hammer to create the shape needed; it is helpful to note that hammering may also be referred to as 'cold forming' (Papadimitriou 2008:283).

Ingots of the LBA tend to adhere to two characteristic forms: oxhide and plano-convex (also known as a 'bun' ingot).[6] The most substantial archaeological evidence for the existence of these ingots has come not from ancient metalworking centers, but rather from a few LBA

[6] These are not the only ingot shapes; other types include bars and rounded slabs.

shipwrecks off of the southern coast of ancient Anatolia.[7] These wrecks at Uluburun and Cape Gelidonya have been instrumental in providing insight on the movement of metals in the Eastern Mediterranean during the LBA due to the large quantities of copper oxhide ingots, various bun ingots, and scrap bronze that were found at these underwater sites (Pulak 2010:863-876; Bass et al. 1967:52-83; Bass 2010:800). Discussion of these shipwrecks is continued in **§2.2**.

To summarize, the metalworking industry began with the manipulation of copper, which transitioned to the use of bronze (first, arsenical-, and later, tin-bronze) once alloying technology was achieved. Tin-bronze became the dominant copper alloy in the LBA; however, tin is not a native resource to the Aegean, so where did the tin in Aegean tin-bronzes come from? With a general understanding of the logistics of bronze and bronze production, we can turn to the matter of tin and trade.

[7] There are instances of oxhide ingots found on Crete and Cyprus, but in less quantity; Gale and Stos-Gale 1986:81-100.

CHAPTER TWO

Tin Provenance and the LBA Metals Trade

Fig. 3 Satellite image showing the main tin deposits exploited in antiquity (purple): Cornwall, Brittany, Erzgebirge, Iberia, The Taurus Mountains. Also shown are the two major sites discussed in **Chapter 3** (yellow): Mochlos and Nichoria; made using Google Earth.

2.1 Introduction

When investigating the production of tin-bronze in the Aegean, the acquisition and distribution of tin, one of the two essential components of tin-bronze, are the most difficult to ascertain. Tin is also quite rare within the archaeological record; there are a few instances of objects made of pure tin (see **§2.3**) spread across the Aegean and Eastern Mediterannean, but it cannot be determined definitively if they were made by the Myceneaen culture on the Greek Mainland. If the Mycenaeans, or even the Minoans on Crete, were using tin to make tin-bronze and tin objects in the LBA, how is this reflected in the archaeological record? It is best to begin by examining where tin is formed in nature.

2.2 Bronze Age Tin Sources

Geographically, cassiterite is a rare-forming mineral with very few exploitable deposits world-wide, and even fewer deposits were known in the Bronze Age. Some substantial deposits that could possibly have contributed to the Aegean include the following: Cornwall in the southern part of the United Kingdom; Brittany in northern France; the western coast of the Iberian Peninsula; the Erzgebirge in central Germany; the Taurus Mountains in south-central Turkey; as well as a few more minor deposits (see **Fig. 3**; Penhallurick 1986). The matter of which source(s) yielded tin for Aegean bronzes, however, is largely still a work in progress.

Copper is less of a point of confusion, since it is one of the most-frequently occurring minerals in the world (Muhly 1973:173). Within the Eastern Mediterranean and the Aegean itself, a number of copper ore sources exist, with the most prominent being the mines of Cyprus and at Lavrion in Attica (Muhly 1973:187-199). There are also smaller supplies within the Cyclades (see **§3.1**), and copper may have even come to the Greek Mainland from as far west as Sardinia (Muhly 1973:183-187).

Literary sources from ancient authors, such as Herodotus (c. 484-420s BCE; Camp and Fisher 2002:12), reveal that the later Greeks seemed to know where their tin was coming from:

> [...] οὔτε γὰρ ἔγωγε ἐνδέκομαι Ἠριδανὸν καλέεσθαι πρὸς βαρβάρων ποταμὸν ἐκδιδόντα ἐςθάλασσαν τὴν πρὸς βορέην ἄνεμον, ἀπ᾽ ὅτευ τὸ ἤλεκτρον φοιτᾶν λόγος ἐστί, οὔτε νήσους οἶδα Κασσιτερίδας ἐούσας, ἐκ τῶν ὁ κασσίτερος ἡμῖν φοιτᾷ.

> [...] for neither do I believe that the river called Eridanus by the barbarians lets out into the sea towards the northern wind, from which it is said that amber is imported, nor do I know any islands as being the Cassiterides, from which our tin is imported.
>
> *Hdt. 3.115.1*

This group of islands dubbed the 'Cassiterides', deriving from the Ancient Greek word *κασσίτερος* for tin, are supposedly one of the main suppliers of tin to the Greek world during the Classical period (480-323 BCE; Camp and Fisher 2002:18-19) and later. With Herodotus' account, we can infer that, while the origin of the tin imported to the Aegean is known by name, it was not known to the Greeks exactly where that place was, other than that it was somewhere "far away":

> ἐξ ἐσχάτης δ᾽ ὦν ὁ κασσίτερος ἡμῖν φοιτᾷ καὶ τὸ ἤλεκτρον.
>
> But certainly the tin and amber is imported to us from the edge.
>
> *Hdt. 3.115.2*

Strabo, who was writing a few centuries later than Herodotus, demonstrates a clearer understanding of the location of these islands during the Hellenistic period:

> γεννᾶσθαι δ᾽ ἔν τε τοῖς ὑπὲρ τοὺς Λυσιτανοὺς βαρβάροις καὶ ἐν ταῖς Καττιτερίσι νήσοις, καὶ ἐκ τῶν Βρεττανικῶν δὲ εἰς τὴν Μασσαλίαν κομίζεσθαι.
>
> And [Posedonius says] that [tin] was produced both in the barbarous lands beyond the Lusitanians and in the Cassiterides islands, and indeed was brought from the British Isles into Marseille.
>
> *Strab. 3.2.9*

In accordance with Strabo's description, modern scholars have determined that the Cassiterides likely referred to the southern region of England, specifically Cornwall and the Isles of Scilly off the coast (Warmington and Millet 2015). Strabo also reveals here that Greece was simultaneously receiving tin from the "barbarous lands beyond the Lusitanians," who were a people living in the western part of the Iberian peninsula. This coincides with the passage on tin mining cited in **§1.4**, which is taken from the same section of Strabo's *Geography*.

2.3 Long-Distance Trade

The acquisition of tin from these regions in the Classical and Hellenistic periods is more certain than can be determined for the LBA, in large part thanks to the surviving literary record; however, it is not so simple for determining tin provenance in the LBA. In the past few decades, a technique called *isotope analysis* has been increasingly employed to determine the origins of metals. Through this process, a sample of tin, or any alloy containing tin, can be analyzed and cross-referenced with other tin samples of a known provenance based on their chemical compositions. A recent study in the compositions of LBA tin ingots from Kfar Samir South, an underwater site off the coast of the modern city Haifa in Israel, has presented a similar signature to that of British tin, which suggests that this particular trade between the Eastern Mediterranean and Western Europe had been in effect as early as the LBA (Berger et al. 2019:29-38).

This same study included a rare Aegean terrestrial tin ingot from the Minoan settlement on Mochlos, a small island off the east coast of Crete that was connected to the larger island up until the Hellenistic period. Mochlos saw the peak of its activity in the Neopalatial period (1700-1425 BCE); during that time, Mochlos served as a vital point of trade between the Aegean and the Near East, particularly with Cyprus and the Levant (Berger et al. 2019:3; Soles 2008:145). This ingot, dating to c. 1530-1425 BCE, was found in a severely corroded state under a pithos in a store room. It is thought that this ingot, along with a bronze trident that was also found in this spot, were placed in the foundation during construction of the building as offerings (Berger et al. 2019:3; Soles 2010:332). The placement of the trident with the ingot is intriguing, as it seems like it was meant as protection for the precious metal. This coveting of a single ingot speaks greatly to the rarity of tin, and just how valuable it was to the people at Mochlos. However, it is more likely, perhaps, that the trident was merely scrap taken from a worn piece of equipment, and was hidden away with the tin ingot for safe keeping or to be used at a later time.[8]

Ultimately, it was concluded that the Mochlos ingot, although displaying numerous similarities to the compositions of the Israeili ingots, was more-likely to have come from a source in central Asia, such as Afghanistan or the Zagros mountains in Iran (Berger et al. 2019:29). Although Mochlos has yielded only one terrestrial tin ingot for Crete so far, several more can be accounted for amongst the remains of two LBA shipwrecks, both located off the southern coast of Turkey. This is a major indicator that tin, along with copper, bronze, and other types of raw material goods were actively being traded over far distances during this period in the Eastern Mediterranean.

While there is scant evidence for the trading of metals during the Early Bronze Age (EBA; 3000-2000 BCE; Camp and Fisher 2002:18-19) between the Aegean and more distant civilizations, other types of goods found around the Eastern Mediterranean imply long-distance trade; in the Late Neolithic period (LN; 5300-4500 BCE), the island of Melos saw an increase in long-distance trade of obsidian, in particular. Through X-Ray Fluorescence and Mass Spectrometry, it has been determined that a substantial quantity of obsidian artifacts found at the northwest Anatolian site of Coşkuntepe were Melian (Perlès, Takaoğlu, and Gratuze 2011:43). This indicates that capabilities for engaging in trade over far distances by sea were already established at least by the LN, and surely by the EBA.

[8] Thomas Palaima has brought it to my attention that the likelihood of the trident and tin ingot constituting a foundation deposit seems “far-fetched”, as the purpose of a trident as attested in the historical Greek lexicon is entirely for fishing purposes, and might not therefore be viewed as a weapon ‘protective’ of the tin ingot. Furthermore, Joann Gulizio has noted that foundation deposits are characteristic of periods later than the Bronze Age, and tend to include objects clearly identifiable as ritual in purpose.

The discovery of the shipwreck at Cape Gelidonya, Turkey indicates that long-distance trade had persisted through the LBA. The ship sank c. 1200 BCE while carrying a large quantity of various metals, including copper oxhide and bun ingots, bronze bun ingots, a corroded white substance identified as tin oxide (Bass et al. 1967:34-35, 41), and a number of broken bronze tools and scrap, probably to be recast. A close examination of the personal effects on board revealed that the ship and its crew were from the Near East, most-likely Phoenician (Bass 2010:800-802; Bass et al. 1967:164). The exact quantity of tin onboard the Cape Gelidonya wreck is difficult to assess; tin ingots in an underwater environment normally would corrode down into a powdered state and wash away; however, some evidence for tin ingots was preserved as a result of it being trapped under larger copper ingots, but the number of tin ingots that were originally being transported in unknown. (Bass et al. 1967:83). Bass et al. has concluded that the ship was following a route that was typical in the LBA from a Phoenician port towards the Aegean, which assumes that at least some of the metal products of the ship were to be traded with the Mycenaeans (Bass et al. 1967:163-167).

Similarly, the wreck near Kaş, Turkey (late 14th century BCE), more commonly known as the Uluburun[9] wreck, is believed to be Near Eastern, and represents large-scale exportation of metals out of this region into the Mediterranean. This wreck, thought to have been following a route akin to that of the Cape Gelidonya ship, has yielded one ton of tin, which is substantially more than what remains at Gelidonya (Pulak 2010: 864-871). The tin ingots found at the Uluburun site had been broken into smaller chunks, each inscribed with a mark that was executed upon reception before being taken onto the ship. Through the placement of these marks on the ingot

[9] Uluburun is Turkish for “Grand Cape.”

pieces, it has also been discerned that the segmentation of the ingots had occurred before loading, rather than as a result of trauma from the wreck or corrosion over time (Pulak 1988:36). These broken ingots seem to indicate that the tin was collected throughout the duration of the voyage as a form of payment, perhaps as barter. This notion is further supported through lead-isotope analysis[10] conducted upon the finds from the wreck that has revealed the tin onboard the Uluburun ship to originate from two sources: the Taurus Mountains in Turkey and Afghanistan (Pulak 2010:866).

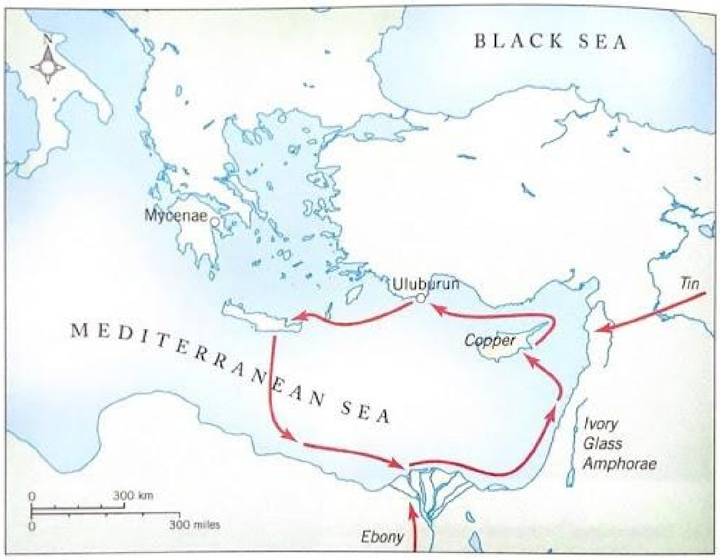

Fig. 4 Supposed route of the Uluburun ship; Cunliffe 2008:200.

Although Levantine ships such as these must have sailed to Cretan ports, it cannot be said how often, if at all, these ships would have made the trip all the way to the Greek Mainland. Considering that their cargoes were also destined for civilizations on the northeast coast of Africa, such as Egypt (see **Fig. 4**), sailing too far into the Aegean seems almost inconvenient, especially since the delivery of any products to the mainland could have easily been handed over to the merchants of Crete; evidence indicates an established trade route between Crete and the mainland

[10] An analysis performed by focusing on the lead isotopes in the metal. The resulting data can then be compared to lead isotopes present in various sources of tin to find the closest match.

through the Cycladic islands around the beginning of the Late Cycladic (LC) period (Gale, Stos-Gale, and Davis 1984:396).

Tin may have also been traded into the Aegean in conjunction with the amber trade from the north. During the LBA, the Baltic region of northeastern Europe dominated the amber trade with the Aegean (Muhly 1973:249). The earliest evidence for this contact is a late-17th century amber necklace, found within Grave Circle B, the earlier of the two shaft grave cemeteries near the Mycenaean citadel (Muhly 1973:249; Penhallurick 1986:132). As demonstrated in **§2.1**, it was known by the time of Herodotus that amber came from lands far away, as did tin:

> [...] τὴν πρὸς βορέην ἄνεμον, ἀπ᾽ ὅτευ τὸ ἤλεκτρον φοιτᾶν λόγος ἐστί [...]
>
> [...] towards the northern wind, from which it is said that amber is imported [...]

and

> ἐξ ἐσχάτης δ᾽ ὦν ὁ κασσίτερος ἡμῖν φοιτᾷ καὶ τὸ ἤλεκτρον.
>
> But certainly the tin and amber is imported to us from the edge.
>
> *Hdt. 3.115.1-2*

Therefore, it could be the case that tin was coming from sources in central and western Europe by proxy of the amber trade. Since amber was transported to the Aegean through the Adriatic Sea, a route which is evidenced by the Mycenaean ceramic finds on Sicily (Vagnetti 2010:891-892), it is difficult to determine exactly where the tin would have come from. Muhly (1973), however, suggests that the style in which amber beads from the Aegean were carved reflects that of the Wessex culture of prehistoric Britain, thus arguing that any Aegean tin resulting from this trade would have come from the Cornish deposits (Muhly 1973:249).

There is, however, a slight issue with the notion of tin acquisition by trade with Sicily that is worth noting. According to A. Vianello and R. H. Tykot, the indigenous population of Sicily during the Aegean LBA (Sicilian EBA-MBA) was not likely alloying tin with copper themselves; they have suggested that the sudden appearance and rapid growth in bronze and bronze objects in this period is indicative of an import-only basis of obtaining bronze, which is attributed to the lack of evidence available in the archaeological record for prior experimentation with bronze alloying (Vianello and Tykot 2017:405). Therefore, it would seem impractical that the indigenous Sicilians would import tin solely for trade with the Mycenaeans if they did not use it themselves.

2.4 The Tin Problem

All of the presented evidence for tin trade shows that the route from the source of the tin to the Mycenaean smithy is in no way clear-cut or direct, making it difficult to determine provenance. It was mentioned briefly that isotopic analysis has yielded results for some artifacts, which has revealed that tin was not supplied by any single source; the ingot from Mochlos, in particular, has also demonstrated that tin ingots were traded with Crete. Since ingots of tin have yet to be found terrestrially anywhere else in the Aegean, this raises the question of where all of the tin has seemingly disappeared to.

As stated previously, the ingots on the Uluburun and Cape Gelidonya wrecks are largely gone due to corroding and dissolving into the salt water. The ingots that do survive were protected by other cargo items, such as the copper oxhide ingots, shielding them from the oxygen in the water. This demonstrates that tin is a more easily-corroded metal than copper, or even bronze, as the bronze objects also suffered less degradation than the tin. This explains why there is a larger quantity of surviving copper and bronze ingots from these ships than tin, but what is the evidence for tin on land? First, note that the Mochlos ingot also exhibits signs of extreme degradation, as indicated by its powdered state; this demonstrates that tin corrodes similarly on land as in water.

Additionally, there is a notable decline of copper and bronze ingots found in terrestrial contexts, and this can logically be attributed to the idea that ingots were meant to be used. The sizable cargoes at Uluburun and Cape Gelidonya represent stock for sale or delivery, so it is expected that these products would be carried in larger quantities. Once they had reached the smithy, however, they were likely to become bronze tools and other objects as soon as possible. Regardless, it is still puzzling that only one terrestrial ingot has been unearthed between Crete and the Mainland.

Tin also appears across the Aegean in the form of objects of pure tin, like the exceptional tin bangle at Thermi on Lesbos (Tylecote 1976:14), or Mycenaean tin-foiled vessels (Immerwahr 1966). It is tempting to justify the bangle as being an Anatolian import due to the island's proximity to the Ionian coast, but the tin vessels pose a slightly more difficult problem. This practice appears to be Mycenaean, since they predominantly belong to several Late Helladic (LH) sites, but some have been found on Crete, Cyprus, and Rhodes (Immerwahr 1966:381; Penhallurick 1986:132-133). There is very little to be said about these vessels regarding their production (i.e. whether they are produced by Mycenaeans or specifically for Mycenaean consumption); still, they represent a peculiar use of such a limited resource as tin.

The Aegean has relied heavily on long-distance trade for resources such as obsidian and metals since as early as the Neolithic period. Even though tin appears widely in tin-bronze across the Mediterranean, it is an especially rare mineral resource; this is even more apparent when compared to the abundance of copper sources available to the Easter Mediterranean. While tin is fairly well attested in the cargoes of the ships at Uluburun and Cape Gelidonya (although still less in quantity than either copper or bronze), the terrestrial evidence that follows in **Chapter 3** yields a stark contrast in findings.

CHAPTER THREE

Metalworking Centers in the Aegean

3.1 Introduction

The Eastern Mediterranean trade in metals, particularly tin, has been discussed in the context of the Uluburun and Cape Gelidonya shipwrecks near Turkey, as well as through the presence of a single ingot of tin discovered on the Cretan island of Mochlos. This chapter explores the evidence on land for bronze-working in the Bronze Age by examining the metalworking industry in each of the three main cultural areas in the Aegean: the Cyclades, Crete (the Minoans), and the Greek Mainland (the Mycenaeans).

3.2 The Bronze Industry of Crete and the Cyclades

The excavations at Mochlos have provided a great deal of evidence for the metallurgy of Crete; however, given that the bulk of these finds are dated to the Neopalatial period (see **§2.2**), it is necessary to begin the exploration of Minoan metallurgy by first examining the Early Minoan (EM) period. The EM site of Chrysokamino, located south of Mochlos, along the Gulf of Mirabello, provides a great deal of evidence for the earliest-known copper smelting performed on the island (Betancourt 2008:105). At this site was a metal workshop, identified by the presence of numerous cupriferous slags deposited in a pile. These slags are examples of crucible slag, and demonstrate that the metalsmiths engaged in smelting metallic copper directly from the ore, rather than simply melting ingots or scrap pieces (Betancourt 2008:106-108).

Lead-isotope analysis has revealed that the copper ores were imported from the north, from either the Cycladic island of Kythnos or Lavrion in Attica on the mainland (Betancourt 2008:108). Important to note is that these ores demonstrated no amounts of arsenical impurities, yet the prills of copper present in the slags contain trace amounts of arsenic; this indicates that metallic arsenic must have been introduced to the copper deliberately at some point during the smelting process (Betancourt 2008:110). This provides sufficient evidence for the production of arsenical copper (or arsenical bronze) on Crete during the EM period. It is also interesting to note that there is a lack of evidence for any further metallurgical processes having taken place after the smelting phase, suggesting that Chrysokamino specialized in this part of the process in particular (Betancourt 2008:110-111).

As stated in **§1.5**, smelting tended to be done in close proximity to the mine, so it is perplexing that the copper ores from Lavrion were exported elsewhere for smelting; this also appears to be the case for copper ores from Kythnos and another island called Seriphos. According to C. Doumas, it was likely easier and more profitable for these islands to outsource copper smelting to installations such as Chrysokamino, where the wood resources necessary for such activities had not yet been depleted (Doumas 2010:103). Regardless, it is apparent that the metal industry of Crete was intrinsically tied to and dependent upon the Cycladic islands, especially concerning the acquisition of metal resources. In particular, the settlement of Ayia Irini on Kea (ancient Keos) seems to have played a major role as a "processing port" in transporting copper from Attica to Crete (Wiener 2013:156).

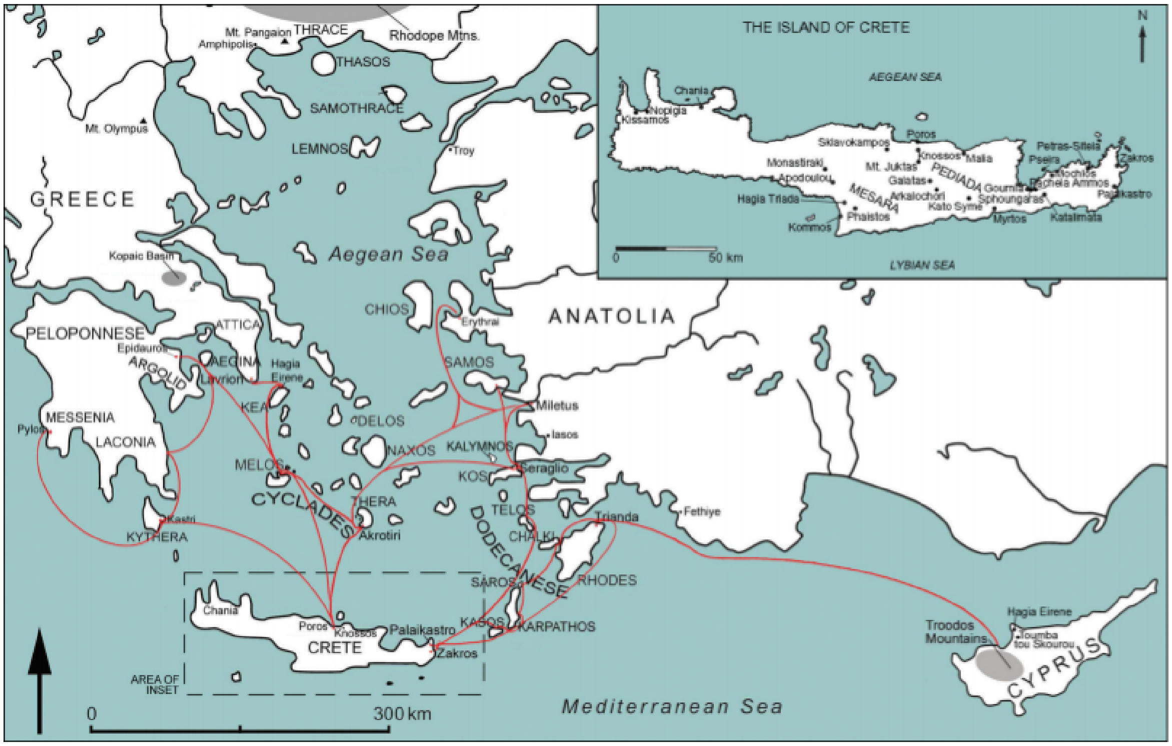

Fig. 5 Map of the Aegean showing Minoan trade routes, including the route to Lavrion through Melos and Kea; Wiener 2013:153.

In the early phases of metallurgy on Kea, evidence at Ayia Irini indicates the working of lead in the EBA, while the nearby settlement Kephala shows evidence for copper-working as early as the LN period (Renfrew 1967:4, 14). By the early Middle Bronze Age (2000-1600 BCE; Camp and Fisher 2002:18-19), Ayia Irini had been smelting copper ores from the source at Lavrion (Gale, Stos-Gale, and Davis 1984:400). Kea is significantly more geographically convenient to the mines of Lavrion than Crete is, being about an hour away by modern ferry; this closeness facilitated an exchange in resources with the mainland, evidenced by the presence of mainland pottery at the site (see **Fig. 5**; Wiener 2013:155). However, despite this proximity to the mainland, Ayia Irini exhibits a great deal of *Minoanization*, a phenomenon in which various aspects of Minoan culture, such as pottery shape and decoration (Wiener 2013:155), are implemented in an area beyond Crete; indeed, a fair amount of Minoan style pottery of the early Middle Minoan period has been found at Ayia Irini on Kea, more so than some of the other islands further south. These vessels represent established contact with the Minoans on Crete, which certainly included trade in copper from the Lavrion mines (Abell 2016:77; citing Davis 1979 and Gale 1998).[11]

During the Neopalatial period of Cretan metallurgy, there is a shift away from the production of arsenical copper and an increase in that of tin-bronze. The settlement at Mochlos was clearly engaged in metallurgical activities, as evidenced by the great volume of metal artifacts found across the site. There are several early LBA metal hoards at Mochlos, including the one consisting of the bronze trident and tin ingot discussed in **§2.2** (Soles 2008: 152-154); this hoard is of particular interest due to the presence of pure, metallic tin, a rarity in the Aegean archaeological record. Although it was deposited in a hoard context in a building not as strongly associated with metallurgical practices, this ingot, along with a copper oxhide ingot from another hoard (Soles 2008:154-155), represent the ability to alloy tin-bronze if desired. However, it should be noted that excavations prior to the discovery of this lone tin ingot have determined that pure tin is otherwise absent among all other metal finds at Mochlos.

In what has been dubbed the Artisans' Quarter, the area known as Building A exhibits the majority of evidence for copper and bronze working, including ingot fragments, scrap, and cast-off, or *waste*. It is noted by Soles and Stos-Gale (2004) that among the waste, a lack of samples of tin spill suggests that alloying of tin-bronze did not occur at the site at this time; this would mean that all tin-bronze objects cast at Neopalatial Mochlos were made from re-melted scrap (Soles 2004:48). As previously addressed in **Chapter 2**, tin is geographically distant from the Aegean, and therefore must have been a rare and coveted commodity; the attempt to hide the

[11] Joann Gulizio has mentioned the exciting possibility of an increased quantity of EBA metallurgical evidence from the 2018-2019 season at Dhaskalio on Keros. Hopefully these findings will shed further light on the connection between Minoan and Cycladic Metallurgy throughout the Bronze Age.

tin ingot (found in Building B, adjacent to Building A) under a pithos also alludes to the importance placed upon tin as a resource (see **§2.3**). The absence of tin within the primary metalworking area of the site, in the form of waste or any additional ingots, is quite perplexing, and seems to indicate that the Minoans at Mochlos were not alloying tin-bronze.

3.3 Mycenaean Metallurgy and the Findings at Nichoria

The mainland exhibits similar circumstances to Crete regarding the lack of evidence for tin in a workshop context. Unlike Crete, no examples of tin ingots have been found in Mainland Greece; pure tin exists here only as the coating on the aforementioned tin-foiled vessels characteristic of the Mycenaean culture (see **§2.3**). It has been mentioned that the lack of tin ingots may be due to their use in metalworking or inability to withstand corrosion, yet ingots of copper and bronze are not nearly as scarce. For instance, the Poros Wall hoard at Mycenae was found to contain numerous copper oxhide ingot scraps and a single bun ingot of tin-bronze (Blackwell 2018: 531), and two bronze slab ingots were identified at Tiryns (Brysbaert, Siozos, Vetter, Philippidis, and Anglos 2017:52; Mangou and Ioannou 2000:208).

There does, however, appear to be fewer bronze ingots in the record than copper oxhide ingots (Mangou and Ioannou 2000:208); perhaps this may be attributed to less need for storing bronze as ingots, as it was likely cast as the desired object form upon alloying or reception. Generally, less objects, such as tools and weapons, were made of pure copper in the LBA than bronze, so it would be fitting to have more copper ingots ready to be alloyed than bronze to be cast. Regardless, there would need to be tin in addition to copper if this were the case, and tin remains missing in ingot form.

If tin ingots or cassiterite ores were being implemented in bronze metallurgy on the Greek Mainland in the LBA, presumably byproducts of this would be present in the archaeological record, such as spill or slag. Examples of tin smelting slags (dating to around 1600 BCE, which is contemporary with the Aegean LBA) have been examined at Caerloggas in Cornwall (Tylecote, Photos, and Earl 1989:435). These slags can serve as a proxy for understanding tin slag in the Aegean, as Cornwall is a potential source of tin for the Aegean during this period (see **§2.1**).

Even at Caerloggas, a site very near to a viable source of tin, few slags have been found. Slag produced by smelting metal ore is primarily iron and silicon (Tylecote 1976:5), so it is expected that tin slag would not corrode in the same manner as metallic tin; therefore, there must be another reason for such a small sample. Smelting cassiterite ores with charcoal would have yielded a high concentration of tin, producing a low quantity of slag (Tylecote et al. 1989:435-437), which is indeed true of Carloggas. However, this cannot be considered a sufficient explanation for the lack of tin in the Aegean, since remains of the prehistoric tin smelting are present in Cornwall (regardless of how little), but not in Greece. In this case, logic would dictate that, if the same processes were taking place in the Aegean, the evidence would also be similar, yet it is not. It must be inferred, then, that there was no cassiterite smelting happening in the Aegean at this time.

With this in mind, it is important to note that bronze production could have still occurred if the tin was imported solely as ingots and alloyed with copper. Evidence for the presence of such ingots has already been thoroughly examined, but ingots are not the only features of the alloying process. As stated in **§1.5**, there is a second type of slag, called a crucible or melting slag. These slags are produced during the melting of a metal that has already undergone smelting, such as an ingot, and are much richer in silica than smelting slags (Tylecote 1976:19). To better understand these objects and what they reveal about the bronze-working processes of the mainland, we must turn to the LBA settlement of Nichoria in the Peloponnese.

Nichoria is located along the Messenian Gulf, on the eastern side of the Aigaleon mountain range, denoting the settlement as part of the Further Province of the kingdom of Pylos (see **Fig. 6**; Chadwick 1973:276-278; Palaima 2000:10). Due to the high volume of bronze and bronze working objects found at the site, along with other determining factors, Nichoria has been identified as the likely location of the Pylian town of **ti-mi-to-a-ko,*[12] signified on a number of tablets containing the Mycenaean Greek script, Linear B (Shelmerdine 1981:319-321).

Fig. 6 Satellite image showing locations of the palace at Pylos and Nichoria, separated by the Aigaleon Range; made using Google Earth.

[12] It has been proposed that the etymology behind this place name is derived from the abundance of *terebinth trees* that grew in the area during the Bronze Age; Palaima 2000:14-17.

The Linear B tablet, PY Jn 829 (see **Fig. 7**),[13] found at the Palace of Nestor at Pylos, is a document written in Mycenaean Greek (the precursor to the later Ancient Greek language) that lists allotments of bronze to be given to the palatial center by designated satellite cities (Nakassis 2006:267; Palaima 2015:632). On this tablet, **ti-mi-to-a-ko* appears in the locative case (as well as the other settlements) as *ti-mi-to-a-ke-e,* meaning "at **ti-mi-to-a-ko*", to indicate where the bronze was sent from. It can be inferred, then, that the settlements listed on the tablet were producers of bronze and bronze products for the central power at Pylos during the late LH period (Shelmerdine 1981:323); this especially includes **ti-mi-to-a-ko,* or Nichoria, where at least one hundred slags alone have been identified (Cooke and Nielsen 1978:183).

Although the number of slags may seem numerous, the metalworking industry at Nichoria was small-scale, which is attributed to the site's status as a "provincial town" (Cooke and Nielsen 1978:182-183; also see Nakassis 2006:277), suggesting that the majority of metal production must have been happening at the palatial center; this is further supported by the contents of PY Jn 829. However, there is still a great deal of metallurgical materials from Nichoria to explore for the purpose of identifying bronze production, nearly half of which have been identified as scrap or waste objects (Catling and Hughes-Brock 1992:620). Within that group, a total of seventeen slags have been identified as either copper or bronze, and were subdivided into smelting and crucible slags; the majority of these were from melting, but there were, in fact, a number of copper smelting slags found as well (Cooke and Nielsen 1978:183).

[13] PY designates the tablet as having come from Pylos, and Jn as concerning metals.

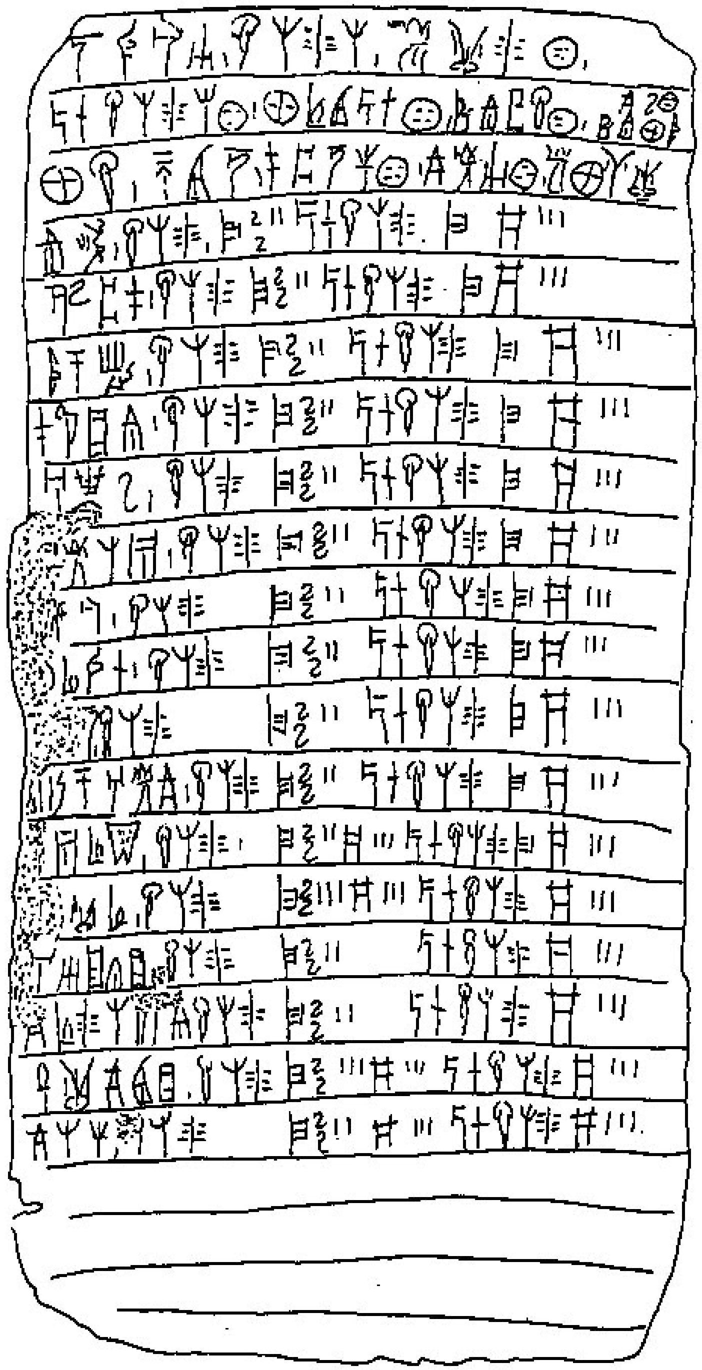

Fig. 7 PY Jn 829;[14] image from
http://www.dimos-pylou-nestoros.gr/museum-chora-room-1.html

[14] Line .13 translation: "at **ti-mi-to-a-ko ko-re-te* BRONZE 2kg. *Po-ro-ko-re-te* BRONZE 0.75kg"; Palaima 2015:633

Note that there is no mention of tin slags present at Nichoria; that is to say, no slags, either crucible or smelting, contain only metallic prills of tin (Rapp et al. 1978:179). Examples of bronze crucible slags found at the site have remnants of metallic tin, which provides evidence for a loss of tin during the melting and casting processes (Cooke and Nielsen 1978:187-188), yet this cannot be construed as a sign of tin metallurgy, as these prills never occur in slags free of bronze. Rather, this seems to indicate that at no point in time was tin metallurgy a practice at Nichoria (Rapp et al. 1978:179); therefore, any bronze being worked here was not produced at the site, but re-melted from ingots or recycled scrap.

Another aspect of the tin-bronzes found at Nichoria that implies a reuse of scrap metal is the apparent lack of control over the copper-to-tin ratio within the alloy. Shelmerdine (1981) notes that there is "little correlation between the tin content of an artifact and its function in any period at Nichoria…" (Shelmerdine 1981:323). This seems to imply that no standard ratio was adhered to in the production of these objects, meaning that the bronze workers are unable to manipulate the percentage of tin in a given object; this can only make sense given that the bronze workers are utilizing bronze scrap with varying amounts of tin, and not alloying tin with copper in a controlled manner. Furthermore, Shelmerdine (1981) states that the chemical analyses performed on the objects support this notion (Shelmerdine 1981:323).

Now that the lack of tin in the workshop context and the predominant use of bronze scrap have been discussed, it is imperative to address the reason for this practice. Why were the Mycenaens not producing bronze in the LH period? An exploration into the meanings of bronze hordes across the Mainland and the metal allotment system in the Linear B tablets may provide a solution to this question.

According to N. G. Blackwell, metal hoarding is a practice that typically denotes “periods of socio-economic and political tension” (Blackwell 2018:509); in this case, hoarding bronze would indicate that this alloy was particularly valuable. He argues that various metal hoards found across the Aegean dating to the LBA may suggest not only that bronze was of value during this time of instability, but perhaps also in short supply as a response to insufficient amounts of copper (Blackwell 2018:513). It would also be reasonable to attribute a shortage of bronze to the difficulties of obtaining tin, as outlined in **Chapter 2**; the deprivation of this resource would certainly hinder the Mycenaeans, or whoever supplies their metals, from producing any bronze.

Blackwell also suggests that the allotment system of bronze to and from palatial centers observed in the Linear B tablets supports the possibility of a bronze deficit. This system is known as *ta-ra-si-ja*, and appears to concern metals only in the tablets from Pylos dating to the LH III period (Blackwell 2018:512), which aligns with the general socio-economic collapse of the Aegean and Eastern Mediterranean at around 1200 BCE (Blackwell 2018:510; Drews 1993:3-7). With the overlapping of these events, as well as with the metal hordes (Blackwell 2018:521), it is very likely that the *ta-ra-si-ja* system was implemented by the central power at Pylos to conserve the metal resources within the kingdom during a time of economic hardship (Blackwell 2018:512).

Considering the evidence for bronze working on the Greek Mainland during the LBA, and in particular in the Peloponnese during the LH III period, it is apparent that there was a lack of new bronze being produced by alloying copper with tin. Due to the absence of tin in the archaeological record, whether in the form of casting spill or metallic prills in smelting slags, it is evident that bronze was primarily melted from scrap or, possibly, ingots. This might have been for several reasons as previously outlined, including difficulties in tin acquisition and socioeconomic issues.

Additionally, evidence for a lack of Mycenaean bronze production can be observed in the Linear B tablets beyond the implications of the *ta-ra-si-ja* allotment system, namely the linguistic origins of the Ancient Greek words for copper, bronze, and tin.

CHAPTER FOUR

Linguistic Analysis and Evidence

4.1 Introduction

Evidence for the absence of tin in the Mycenaean workshop, along with evidence for a bronze industry structured around scrap recycling, can be found not only in the archaeological record as metallurgical remains, but in the written record as well. The Linear B tablets from the palace of Nestor at Pylos offer an array of administrative records, among which is the aforementioned Jn 829 (see **§3.3**), a tablet discerning bronze allocations from various provincial towns to the main palatial center. This chapter analyzes the Mycenaean Greek word meaning copper and bronze, and the implications of the Linear B ideogram AES, abbreviated from the latin *aeneus* for copper and bronze. Additionally, a discussion on the apparent missing word for tin in the Linear B corpus is provided, and how its absence in the Linear B records may support the evidence presented in **Chapter 3**.

4.2 The Meaning of Χαλκός

Often, the Ancient Greek *χαλκός* is translated into English as 'bronze', as in these excerpts from Caroline Alexander's edition of Homer's *Iliad*:

> Then Chryses, a priest of Apollo who strikes from afar,
> came to the swift ships of the **bronze**-clad Achaeans,
> bearing untold ransom to set free his daughter...[15]
>
> *Hom. Il. 1.370-372*

> "Therefore now, should a god come here to test you,
> do you in no way wage head-on battle with the immortal gods,
> with any of the others—only if Aphrodite daughter of Zeus
> comes to war, her you can wound with sharp **bronze**."[16]
>
> *Hom. Il. 5.129-132*

[15] Alexander 2015:13
[16] Ibid. 93

In the contexts of these verses, bronze seems to make sense; it is known that Mycenaean armor was indeed made of bronze, exemplified by the panoply at Dendra (Crowley 2008:274, 276). Additionally, bronze swords and daggers can be attested to within the same cache as the panoply (Crowley 2008:276). *Χαλκός* can also refer to copper, however (Beekes 2009:1611), and it has been proposed that the similarities with *κάλχη* 'purple' (also rendered *χάλκη* and *χάλχη*) allude to an original meaning of 'red metal' (Beekes 2009:1612). Only later did it come to mean 'bronze' specifically, usually with armor and weaponry (Liddell and Scott 2013c:880-881); this adaptation was likely influenced by the introduction of the alloy.

The etymology of *χαλκός*, although uncertain (Beekes 2009:1611-1612), can be observed in the older Mycenaean Greek as the form *ka-ko* in the Linear B tablets (Aura Jorro 1985a:308-309): the spelling patterns of the Linear B script dictate that liquid letters, such as *ρ* or *λ* in Greek, or *r* and *l* in English, will not be represented in certain environments, as here before a guttural stop; thus, *λ* is not represented in *ka-ko*. Similarly, Ancient Greek words with a terminal *ς* will drop the letter in Linear B spelling. However, although *χαλκός* can refer to either copper or bronze in Ancient Greek, *ka-ko* does not appear to share this duality, and is primarily defined as 'bronze' (Aura Jorro 1985a:308-309).

Perhaps it is not impossible that the Mycenaeans regarded bronze as being similar-enough to what they had already known as copper, and so they understood both metals to be *ka-ko*. This is not to say that they were unable to distinguish between the two. Rather, assigning the identity of *ka-ko* to bronze might have been done for the sake of simplicity. This becomes more plausible when considering that arsenical bronze, which is also known as arsenical copper, preceded tin-bronze in use, and the knowledge that arsenical bronze is largely copper-based may have influenced the application of *ka-ko* to bronze. This would then include the later tin-bronze, since it was likely recognized as a variant with its comparable looks and qualities (see **§1.3-4**).

Why is it important to understand whether *ka-ko* is meant to identify copper or bronze, or both? While it would be easiest to claim that *ka-ko* was originally copper, but came to be bronze once bronze metallurgy became dominant, the evidence to support this hypothesis is tricky. If the Mycenaeans were producing new bronze, i.e. alloying copper with tin, then this would require the importation of both metal resources. One way in which this might be evidenced is by the ideograms chosen to represent metals. Bronze, or AES (also known by the number **140*; 𐃟), as it is seen on PY Jn 829 is denoted by an ideogram resembling an axe (see **Fig. 8**). Bronze axes are indeed known in the LH period (Melena 2014:4), so it is not surprising that such an identifiable object would be chosen to represent this material, as bronze may have been traded and transported in various forms; this would imply that *ka-ko* does indeed refer to bronze, and not copper (Melena 2014:140).

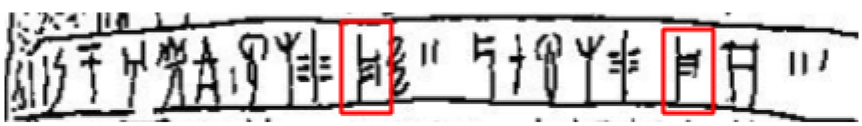

Fig. 8 Line .13 of PY Jn 829 showing the use of the AES ideogram (outlined in red); adapted from image at http://www.dimos-pylou-nestoros.gr/museum-chora-room-1.html

If such is the case, then the ideogram **167* (𐃮) may likely be the representative ideogram for unalloyed copper (Melena 2014:151, 155; Michailidou 2008:524). This is further supported by the ideogram's mimicking the shape of the well-known oxhide ingots, which have never been found to be made of bronze (Blackwell 2018:516). Furthermore, the effort to include both AES and **167* on the same tablet (KN Oa 734; Killen and Olivier 1989:265) seems to provide additional evidence that these ideograms represent an attempt to distinguish between the two metals.[17] Note the ligature on **167+PE* in this variation. This could possibly be an abbreviation of *pe-re-ku*, later Greek *πέλεκυς* 'axe', which also represents a Cypriot measurement of weight equalling ten minas (Melena 2014:151; Michailidou 2008:524). Since Cyprus is a known source of Aegean copper (see **§2.2-3**), perhaps this aids the notion that **167* depicts a copper oxhide ingot.

KN Oa 734

]jo AES *167+PE[[18]

4.3 The Search for Mycenaean Κασσίτερος

As noted previously in **§4.2**, the possible use of two distinct ideograms to denote bronze and copper might be advantageous in proving the production of new bronze in the LH period. However, this process would require the addition of tin, which the evidence presented in **Chapter 3** has shown to be absent from the archaeological record. It is fitting, then, that a definitive Mycenaean Greek word for tin has yet to be identified, as well (Freeman 1999:223; Lindgren 1973:69). As with *χαλκός* and *ka-ko,* it is easiest to first search for a word resembling the Ancient Greek word for tin, *κασσίτερος* (Liddel and Scott 2013a:402).

Κασσίτερος is attested as early as the epic poems of Homer, shown in these excerpts in the genitive form:

> [...] ἀμφὶ δὲ κυανέην κάπετον, περὶ δ' ἕρκος ἔλασσεν
> **κασσιτέρου·** [...]
>
> [...] and on both sides he drove a dark-blue ditch, and around it a fence
> **of tin;** [...]
>
> *Hom. Il.18.564-565*

[17] KN designates that the tablet is from Knossos on Crete.
[18] Killen and Olivier 1989:265.

αἱ δὲ βόες χρυσοῖο τετεύχατο **κασσιτέρου** τε, [...]

And the cows had been made of gold and **tin,** [...]

Hom. Il.18.574

Hephaestus also forges the hero a pair of greaves made from tin, suggesting the practice of tin metallurgy:

[...] τεῦξε δέ οἱ κνημῖδας ἑανοῦ **κασσιτέροιο.**

[...] and he made for him greaves of pliant **tin**.[19]

Hom. Il.18.613

If it is to be understood that the *Iliad* is set in the later part of the LH period, and (originally an oral tradition) likely composed at that time (Visser 2006:430-435), then there is either one of two possibilities: *κασσίτερος* was part of the Mycenaean vocabulary, or it is a later word that was added in as the verses were passed down through time.

Thus far, *κασσίτερος* has no notable origin in Mycenaean Greek documented in the Linear B corpus. The expected rendering would be something like **ka-si-te-ro*; however, the word that comes closest to this rendering is an unidentified, and possibly incomplete word *]ka-te-ro*, which occurs once on the KN Og 5515 + 5518 + 5539 tablet (Aura Jorro 1985b:331; Killen and Olivier 1989:277). This cannot be considered a direct etymology (Freeman 1999:223; Smith 1993:173), as the missing *si* may be the key element in distinguishing this word as the precursor of *κασσίτερος*.

KN Og 5515 + 5518 + 5539

]ka-te-ro L 4 M[[20]

Anna Michailidou proposes that *]ka-te-ro* may be the Mycenaean *καρτερός*, which she defines as a Homeric epithet meaning 'strong', or 'resistant', (Michailidou 2008:525). She suggests that if

[19] Typically 'soft' when referencing cloth, ἑανοῦ can mean 'pliant' when used with *κασσίτερος*; Cunliffe 2012:102.

[20] Killen and Olivier 1989:277.

applied to bronze, it could adopt a meaning of 'reinforced', as bronze is copper fortified with tin (Michailidou 2008:525). There is also the word *ka-si-ko-no* that appears a number of times concerning sword manufacture in the KN Ra series, and once on PY An 128 (Freeman 1999:223), posing the question of whether or not this word has something to do with tin-working. However, this also remains inconclusive due to the dubious etymology (Freeman 1999:223).

There is one final possibility to be discussed, and it is that tin may have been perceived as not dissimilar to lead in the same way that copper and bronze had become associated with the same word. This is not impossible, as it is well attested in Latin that tin is described as "white lead":

> Sequitur natura plumbi, cuius duo genera, nigrum atque candidum. pretiosissimum in hoc candidum, Graecis appellatum cassiterum [...]
>
> Then follows the nature of lead, of which there are two kinds, black and white. The white is most precious, it was called 'cassiteros' by the Greeks [...]
>
> *Plin. 34.16.47*

Lindgren suggests that the Mycenaean *mo-ri-wo-do* (KN Og 1527; Killen and Olivier 1989;276), thought to be the predecessor to the later *μόλυβος* ('lead'; Liddell and Scott 2013b:517), could similarly include tin in its meaning (Lindgren 1973:69). Where this interpretation becomes faulty is when the archaeological evidence for these metals is examined; lead is accounted for, while tin is not.

Thus far, the evidence has been presented as such: The Pylian kingdom seems to have primarily dealt in pre-alloyed bronze, as outlined by PY Jn 829 and the *ta-ra-si-ja* allocations across the Jn series (see **§3.3**). Additionally, the function of *ka-ko* and the ideogram AES as 'bronze', not 'copper', supports this idea. In conjunction with these points, the absence of tin in the archaeological record reflected in the Linear B corpus firmly indicates a metal industry reliant upon recycling and importation, not production.

CHAPTER FIVE

Conclusion

It would seem that both the metallurgical and linguistic evidence support the possibility of a primarily recycle-based bronze industry on the Greek Mainland during the LH period. It has been established in **Chapter 2** that tin ore is a geographically rare mineral, and so acquisition of this resource would have required elaborate trade, comparable to that of amber from the Balkans region. The funerary context of amber at Mycenae, as well as the vessels coated with tin (Immerwahr 1966:381-384, 386-387) would suggest that these objects hold some amount of import. Perhaps the rarity of tin had allowed for the metal to become something of a prestige good in the Mycenaean period, as it almost never occurs unalloyed in any other context.

Even within the workshop, where it might be expected most, tin is astonishingly absent from the archaeological record. This has raised the question of whether bronze production was practiced by Mycenaeans during this period, as it is necessary to alloy copper with tin to form tin-bronze, the dominant alloy of the LBA. First, evidence from Crete and the Cycladic islands was examined in **Chapter 3** to provide a comparison within the Aegean to the mainland evidence. It was revealed that, while copper smelting and bronze working were highly practiced throughout the Bronze Age in these regions, only one trace of possible tin metallurgy has been found to date. The tin ingot found with the bronze trident scrap at Mochlos remains dubious in its ability to either confirm or deny bronze production during Neopalatial Crete; a larger body of evidence is needed to draw any firm conclusion. However, it does seem unlikely, given only one tin ingot across the whole of the Aegean exists.

Next, the evidence for palace-regulated bronze metallurgy at Nichoria was investigated, as well as the implications of the *ta-ra-si-ja* system of allocating bronze to the central power for working at Pylos. It is difficult to determine whether these allotments consist of scrap bronze or ingots, the latter of which might have been produced at the sites of the provincial towns noted on the PY Jn 829 tablet. However, when reviewing the findings at Nichoria, evidence to suggest tin metallurgy in any capacity is completely lacking; that is to say, there is neither smelting of tin ore, nor melting of pure metallic tin. Remnants of metallic tin prills within bronze smelting slags from the site are present, but this tin only occurs within pre-alloyed bronze.

It is plausible that copper may have been added to existing bronze in order to increase the supply, and there are several factors that have determined this. The first is that, as Blackwell has proposed, the Mycenaeans were faced with economic hardship at the end of the LH period, which is attested by the known socio-economic collapse that affected the Eastern Mediterranean at large during this time. He has suggested that the practice of hoarding bronze objects and scrap observed on the mainland, and Crete as well, reflects the need to conserve resources. Additionally, the palatial control over metal distribution recorded in the Jn series displays a similar necessity to ration out metal resources.

The presence of copper metallurgical waste in addition to bronze waste is another indication that copper may have been added to bronze. Little evidence is available for copper weapons and tools beyond the Chalcolithic and the early phases of the Bronze Age, especially in comparison to bronze in later periods. It would be reasonable to find copper metallurgy in the archaeological record with the expectation that evidence for tin metallurgy and bronze production would also be identified; however, as it has been established, there is no such evidence present at Nichoria.

The final determining factor to be discussed is the implications of the Linear B ideogram **167*, which strongly resembles the shape of a complete copper oxhide ingot, such as those found at the Uluburun wreck. As outlined in **§4.2**, **167* could be the designated ideogram representative of unalloyed copper, especially when opposed to the ideogram AES that is understood almost exclusively as bronze. The instance on tablet KN Oa 734 in which **167* appears to be modifying AES could signify the additional alloying of copper to bronze; furthermore, the ligature *+PE*, which possibly indicates a certain measurement in weight, may represent the amount of copper that is to be added.

The socio-economic collapse at the end of the Bronze Age is widely debated as to its exact cause. However, the evidence for the conservation of precious metal resources during this period that have been presented in this paper may shed further light upon this widespread event. While tin deposits are indeed scarce across the world, they must have been exploited with relative ease at one time in order for tin-bronze to become so broadly significant. It may be that tin had reached the Aegean earlier in the Bronze Age, but it is clear that the metal was no longer obtainable in later periods. This suggests that trade in this resource had been cut off; whether that is because of political tensions or simply an over-mining of cassiterite deposits, is difficult to determine. It is clear, however, that the decline in bronze production by the LH period is inherently tied to the downfall of the Mycenaeans.

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