Digital Approaches to Mycenaean Tin Bronze Trade with the Balkans: A GIS and Network Analysis

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I hereby declare that this dissertation is an original piece of work, written by myself alone. Any information and ideas from other sources are acknowledged fully in the text and notes.

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Introduction

The Late Bronze Age (LBA, dating from 1700 to 1050 BCE) in the Aegean world was a dynamic period marked by extensive cultural interactions and technological exchange, particularly in the development of metallurgy. Among these innovations, the widespread distribution of bronze, which is an alloy composed of tin and copper with lower toxicity and greater durability than arsenical bronze, significantly transformed metalworking practices across the Aegean during this time (Papadimitriou 2024, 271–75). This shift of metal practices reflected broader socio-economic changes, such as exchanges of resources and elite display. For Mycenaean society, bronze was more than a functional material, it also served as a symbol of power and transregional connection (Blackwell 2018, 509–10; Day and Doonan 2007, 103; Iacono et al. 2021, 405–9; Papadimitriou 2024, 280–83).

The majority of bronze artifacts found in Mycenaean burials have been analyzed primarily in terms of the social significance of the deceased, often serving as indicators of their social status (Aulsebrook 2020, 242; Day and Doonan 2007, 99). However, despite extensive research on Mycenaean metal artifacts over these decades, the origins and circulation of metals remain underexplored (Aulsebrook 2020, 239–40; Tzachili 2004, 20). Due to geographical factors, mainland Greece lacks native tin bronze deposits, suggesting that there was an interaction between the mainland and external sources through complex trade networks (Day and Doonan 2007, 103; Blackwell 2018, 510). Previous research emphasized the long-distance trade with Anatolia and the Near East, especially the Taurus Mountains in Turkey and the Zagros Mountains in Iran (Huska et al. 2014, 477; Şahoğlu 2005), while recent studies have begun to reevaluate the role of the Balkans as a significant part of this transregional exchange (Bulatovic, Molloy, and Filipovic 2021; Gavranović et al. 2022; Grigoriev 2021; Michael et al. 2023; Sabatini 2016; Tzachili 2004, 21–22, 25; Wójcik 2024).

The focus of this study will be exploring the following research question: How did tin bronze-related materials, technologies, and stylistic practices spread across the Mycenaean culture and the Balkans during the Late Bronze Age, and what spatial and networked patterns can be reconstructed from archaeological evidence? To analyze this main question in greater detail, this study will also question the crucial role of key archaeological sites in this exchange, look at different types of transmission followed by distinct spatial pathways across the region, and then find out the most frequent transmission routes if possible.

This study defines the term “Balkans” geographically as the region bounded by the Adriatic Sea to the west, the Black Sea to the east, and the Ionian and Aegean Sea to the south (Radivojević and Roberts 2021, 198). The primary research area includes Balkan regions where archaeological and metallurgical evidence of Mycenaean-style tin bronze production has been found and mines that could be potentially considered as the source of metal in Mycenaean culture. Additional sites located in Hungary, Turkey, Cyprus, and Italy are also included in the analysis to contextualize the continuity of trade routes between Mycenaean Greece and the Balkans.

While traditional archaeological approaches have provided foundational

interpretations, they are often limited to visualizing and analyzing complex trade networks and changes over time (Guidi, Russo, and Angheleddu 2014; Morgan and Eve 2012). To address this gap, this study aims to reconstruct the spatial and relational dynamics of tin bronze exchange between the Mycenaean culture and the Balkans by integrating Geographic Information System (GIS) and two-mode network analysis. By combining spatial data with network visualization, this research is expected to also seek how such exchange influences local metallurgical traditions and broader social transformation in the LBA Aegean. The structure of this paper will begin with a historical and literature review, followed by methodological and data explanations, spatial and network analyses, and a discussion on the implications of sustainability and connectivity.

Historical and Literature Context

The Mycenaean culture is widely renowned for its advanced metallurgical practices, particularly in the production and use of tin bronze. Bronze items, ranging from decorative objects to weapons and tools, often serve as indicators of wealth and status within Mycenaean society. However, as numerous studies have emphasized, tin bronze was almost absent in mainland Greece, making the acquisition of this essential alloying element a crucial concern in both economic and geopolitical terms, and the source of metals remains one of the key focus areas of current research (Aulsebrook 2020, 242–56; Blackwell 2018, 510; Day and Doonan 2007, 103; Muhly 1985).

Archaeological and scientific research have established that while bronze production was well developed in the LBA, the circulation of tin remains only partially understood. For example, trace analysis methods have revealed fewer tin residues in many bronze artifacts in earlier Minoan contexts, which may reflect the recycling of bronze during this period. Comparably, findings such as a pure tin bead at Armenoi in Crete from Late Helladic ⅢB suggest an increase in tin use at the end of the Mycenaean period (Tzachili 2004, 20–25). Even if the tin bronze became the mainstream at the LBA, evidence like Linear B tablets from Pylos[1] shows a shortage of raw materials, which suggests a relatively complex acquisition of tin, and made it possible to import metals from even farther regions (Huska et al. 2014, 477; Tzachili 2004, 25). One important piece of evidence is the widespread distribution of oxhide ingots, which illustrates the complexity of the LBA trade. These ingots have been found across the Mediterranean, involving Cyprus as the main supplier of metals (Gavranović et al. 2022, 16; Sabatini 2016; Tzachili 2004, 21–27). The uniform shape and composition of these items point to a cohesion of the trade network, in which Mycenae was a key participant.

However, in contrast to the Balkans and the western Mediterranean, Cypriot oxhide ingots were almost absent from the Greek mainland. The majority of oxhide

[1] In the Jn series of Linear B tablets at Pylos, although there were over 200 coppersmiths, the amount of copper they received was approximately 3.5 kilograms (which is considered a small quantity), and 81 of these coppersmiths even not receive raw materials. Data from Tzachili 2004, page 25.

ingots from Cyprus have been discovered in the Balkans, mainly Romania, Serbia, Croatia, and Bulgaria (Gavranović et al. 2022, 16; Sabatini 2016, 35–38), suggesting the existence of a land or maritime route connecting the southeastern and northwestern regions. At the same time, the island of Sardinia in Italy emerged as a major consumption center for oxhide ingots within this metal exchange network. The earliest oxhide ingots found on Crete may also show an east-to-west route linking Cyprus to Sardinia (Blackwell 2018, 514; Huska et al. 2014, 477; Iacono et al. 2021, 398–400, 410–12; Sabatini 2016, 39) [Figure 1]. As the geographic "midpoint" between these two routes, Mycenae has discovered only a few oxhide ingots (Blackwell 2018, 514). This absence may suggest that the LBA bronze trade network originating from Cyprus excluded the Greek mainland. Alternatively, it is possible that there was another separate trade network that existed as the supplier of bronze resources for Mycenae at the time.

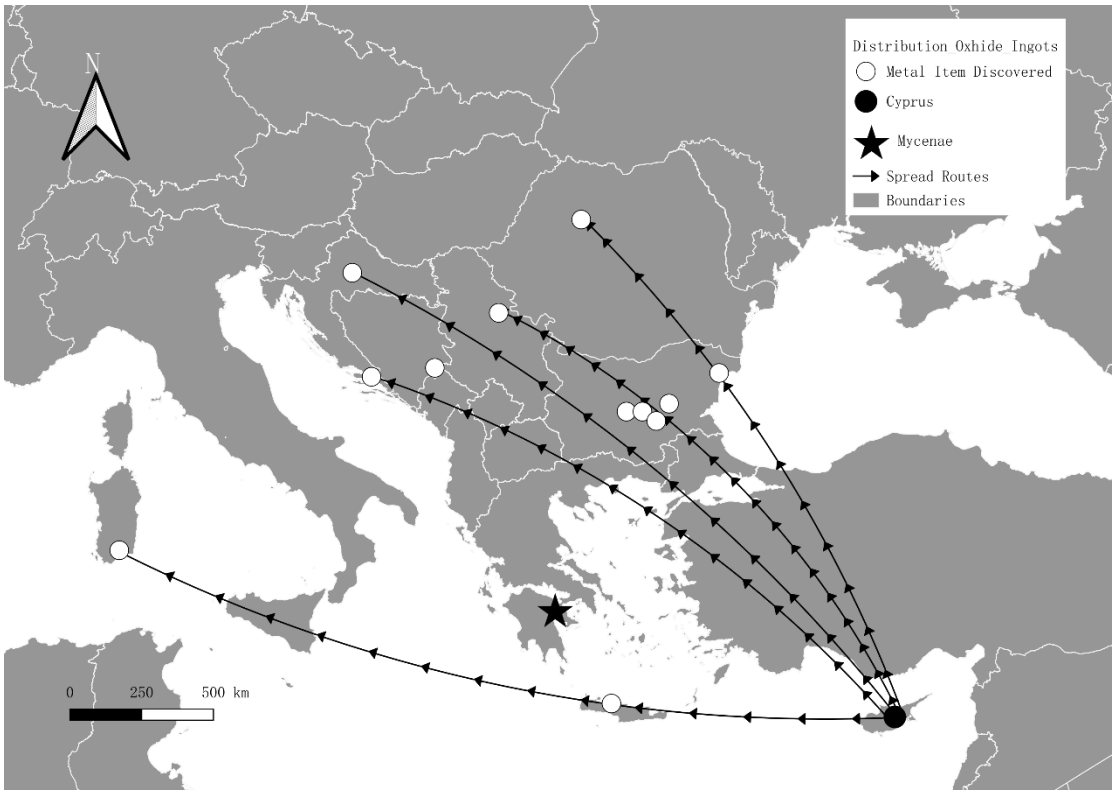

Figure 1: The distribution of Cypriot oxhide ingots (Blackwell 2018; Gavranović et al. 2022; Huska et al. 2014; Iacono et al. 2021; Sabatini 2016). Base map source: geoBoundaries (Runfola et al. 2020).

Tin sources during this period were rare and widely dispersed, making long-distance trade essential for Mycenaean palaces to control raw materials, sustain economic development, and maintain political power (Iacono et al. 2021, 405–12). Given the exclusion of the Greek mainland from the LBA bronze trade network starting from Cyprus, it becomes necessary to explore a potential route to explain the origin of bronze resources in Mycenaean Greece. In this case, the Balkans gradually emerges as a region of growing importance in the supply of metal resources. Recent studies have

shown that placer tin deposits in western Serbia, silver mines in Romania, and copper resources in Bulgaria, all of which have the potential to be the suppliers of metals for mainland Greece (Gavranović et al. 2022, 16; Huska et al. 2014, 477; Radivojević and Roberts 2021, 201; Sabatini 2016, 38–40). Moreover, due to the lack of bronze on the Greek mainland, this research therefore turns to the north, focusing on Mycenaean-style bronze objects found in the Balkans as evidence for the possibility of an existing bronze trade network.

On the other hand, the cultural exchange within this research area was also a crucial aspect of supporting the potential trade network. Previous research suggests that this exchange is evident in various archaeological findings such as burial customs, settlement patterns, ceramic and decorative styles, and the spread of technologies. Cranial non-metric analysis showed the population movement in Greece and the Balkans was a slow process through integration (Michael et al. 2023), which indicates a long-term and continuous contact between these two regions in the LBA period. This process of integration is reflected in both material culture and mortuary practices, especially the similarities in ceramic styles and the convergence of grave goods across the northern Greece and the central Balkans.

Ceramic evidence illustrates that by the 15th to 13th centuries BC, there were clear connections existing between these two research regions. One may need to be noticed is this interaction appears to be intensified after approximately 1200 BC (Bulatovic, Molloy, and Filipovic 2021, 62–68). This chronological overlap with the increased usage of tin bronze in LHIIIB[2] Greece (Wace 1957), which suggests that the cultural and technological links not only enhanced the movement of stylistic traits, but also supported the redistribution of raw materials and metal objects within a broader interaction zone.

Methodology and Techniques

This research is intended to adopt a mixed-method spatial analysis approach, integrating Geographic Information System (GIS) and social network analysis (SNA) tools to examine the LBA tin bronze-related trade involving Mycenaean and Balkan sites. This combination aims to bridge the gap between objective spatial modeling and material-based interpretations to avoid bias reflected by the visualization and limitations of representational understanding (Lock and Pouncett 2017, 5–6; Morgan and Eve 2012, 529–34).

GIS is usually for spatial networks based on geographical location relationships to establish a map for analyzing long-distance interaction (Lock and Pouncett 2017, 2–5; Mills 2017, 385). In this project, GIS is used to identify and visualize the spatial distribution of archaeological sites where bronze artifacts, especially those showing Mycenaean stylistic features, have been found. By mapping these sites with major resource locations such as tin and copper mines, we could understand the broader

[2] The chronology of LH III B may lay into the period from 1300 to 1230 BC.

material landscape in which such exchange occurred. Moreover, the GIS map also includes layers marking regions with shared item styles, burial and settlement customs, or technological similarities between the Balkans and Mycenaean Greece. This will help to identify key areas of likely cultural contacts, and these spatial patterns help highlight sites that may have played crucial roles in this interaction network.

Although GIS is powerful in modeling spatial distribution, its structure or the focus on spatial data may limit the capacity to analyze complex social connections. For example, GIS may reduce the dynamic human experience to static and measurable forms, then overlook movement, affect, and practice that are emphasized by non-representational theory[3] (Lock and Pouncett 2017; Thrift 1996). However, this does not mean GIS is limited to visualization only, spatial analysis techniques such as density analysis or least-cost path modeling could provide insights relevant to trade connectivity, which could be considered in future extensions of this project.

To address these concerns, this study will also introduce a two-mode network analysis using Gephi, in addition to basic spatial analysis through GIS. This network includes one set of nodes representing specific types of Mycenaean-style items like pottery forms, metal tools, or ornaments, and another set representing the archaeological sites where these objects were found. Rather than functioning only as a visualization, the network allows for analyzing metrics such as degree centrality and modularity class, helping to identify which types of artifacts were frequently involved in cross-cultural interaction. For instance, it becomes possible to trace which objects and sites were more active in forming cultural connections in this process. This network is built from a material culture that can reflect shared identities and patterns of technological transmission (Mills 2017, 383–87). Therefore, a two-mode network is suited to the archaeological data of this research by showing complex associations between different categories.

In general, GIS offers a structural foundation to show the proximity and resource locations, while Gephi helps to reveal the dynamic web of relationships based on material culture. By combining the objective spatial modeling of GIS with the relational modeling of Gephi, this project is intended to integrate both physical and social dimensions of trade connecting Mycenaean Greece and the Balkans in the LBA period.

Data Collection and Management

This research begins with a focused collection of archaeological evidence relating to the distribution of Mycenaean-style bronze objects, ornaments, and associated cultural and technological traces across the Balkans. The core aim is to map the material zones of contact between these two regions, with an emphasis on identifying patterns that reveal how and why the Balkans may have played a central role in the transition of metals and cultural forms in the LBA.

The primary materials of interest include Mycenaean-style artifacts such as tools,

[3] Non-representational theory, in this case, focuses more on shared practices, affects and feelings, embodied experiences, or everyday performances, than static maps, patterns, or words.

weapons, ceramics, burial ornaments, and any other related features. At the same time, the investigation also includes signs of Balkan-origin influences appearing in Mycenaean sites, such as burial customs, to ensure a more complete understanding of mutual exchange rather than unidirectional diffusion.

For getting a broader picture of the metallurgical movement, the research also considers extended networks that reach into areas such as the Near East, Cyprus, and Sardinia, particularly in relation to the distribution of oxhide ingots that were discussed before. The presence of these copper ingots in the western and eastern Mediterranean is critical to reconstructing bronze supply chains (Blackwell 2018, 514; Iacono et al. 2021, 410–12; Tzachili 2004, 27). While Cyprus is often identified as a key source of copper, this study explores how the Balkans may have formed a corridor linking these Mediterranean systems to Mycenaean production centers.

The data framework is focused on the studies published between 2004 and 2024, specifically on publications that document bronze items and metal-related sites from this 20-year period. This time frame was chosen to prioritize the most recent findings and interpretations that were informed by lead isotope analysis and spatial studies. At the same time, a set of selection criteria was applied to determine which sites and objects should be included in this research. Artifacts must either originate from the LBA period or be attributed to Mycenaean influence. Likewise, sites were considered relevant if they contained traces of bronze production or consumption that could be tied to interaction with the Aegean world. The result contains 57 geographically wide but thematically focused locations.

During the data collection phase, one may notice that some countries like Serbia, Bulgaria, and Romania have much more detailed information on the target data, and they also tend to have more comprehensive archaeological recording. In contrast, the western and northern regions of the Balkans remain underrepresented in the available literature. This disparity of documentation may be related to a lack of systematic surveys or digitized records, and then this practical issue may influence how interaction networks are modeled and potentially affect the future understanding of the established exchange patterns.

In parallel with the documentation of artifact sites, the research also records data from previous studies on known Bronze Age mining locations, particularly those associated with copper and tin. Many of these mines are in central Balkans, especially in western Romania and central Serbia. When comparing these mining sites and locations where Mycenaean-style bronze items were found, a geographic overlap becomes evident. This suggests that the central Balkans not only supplied raw materials but also acted as a corridor for exchange with Mycenaean Greece. These patterns reinforce the idea that metallurgical interaction during the LBA cannot be understood only through coastal networks, instead, the inland zones of the central Balkans played a significant role in shaping the Mycenaean trade network for the access of bronze.

To support the hypothesis of long-term contact within the research area, the movement of everyday goods and agricultural products alongside the transmission also be considered. While metals form the core of this material network, non-metallic

evidence such as foodstuffs could offer valuable insights into the trade routes and cultural exchange. One notable example is the spread of millet during this period. A north-to-south trade dating to the LBA has been identified in previous research, along which millet spread from the Carpathian Basin through the Morava Valley and eventually reached Greece (Bulatovic, Molloy, and Filipovic 2021, 76). This trajectory aligns with the hypothesis of the importance of the Balkans during the LBA. Thus, this pathway can be regarded as an indirect indicator of transregional interaction. While such items were not included in the core spatial dataset for digitization, they were noted in the metadata table for contextual reference and interpretation of wider exchange patterns.

Following the initial identification and selection of relevant archaeological sites and artifacts, the second phase of the data management involved organizing this information into a systematic and scalable digital format suitable for digital analysis. Each site identified in the previous stage was recorded as an individual entry in a metadata CSV file. The structure of this file was designed to balance flexibility and clarity, so each site included the following fields: site ID and name[4], location coordinates, artifact type and description, material or stylistic provenance (if available), and source reference. It should be noted that most of the location coordinates were sourced from official site registries or excavation reports, however, for sites without clear geographic information, the central point of the respective region will be chosen as the coordinates. The potential inaccuracies and ambiguities introduced by this method should be taken into account in the subsequent discussion.

In order to maintain version control and ensure future sustainability, a consistent file-naming structure was adopted. All metadata files were labeled using the format *Dataset Content_Version Number_Date*. For example, the initial version of the core file containing site metadata was saved as *LBA_Mycenaean_Balkan_Sites_Metadata_V1_20250415*, which allows each change to be traced and reverted if necessary. Ultimately, the structure and management of this dataset aim to provide a transparent and replicable foundation for interpreting the cultural and material flows across the complex geography of the LBA Mycenae culture and their contacts with the Balkans. All datasets, GIS project files, network analysis outputs, and figures used in this project are available on GitHub: https://github.com/ZhaoW923/Mycenaean-Balkans-Bronze-Project.

Overall, both the selection of sites and the data management ensured accuracy, reliability, and transparency as much as possible. However, it is equally important to pay attention to vague, incomplete, or underdiscussed information during the following stages of analysis. Acknowledging these uncertainties is essential to minimize potential ambiguity in the interpretation of the final conclusions.

[4] Note on site names: For technical compatibility and formatting clarity, diacritical marks (e.g., ü, č) have been removed from site names in the dataset and GIS/Gephi files. The full names with correct diacritics are preserved in the main text when needed,

Visualization and Analysis

This section contains two GIS maps based on the geographical coordinates and documentary sources. This first [Figure 2] will show mineral resources, metal discovery, and associated archaeological sites in the target research area, which covers a wide range of regions from southern Greece to the Apuseni Mountains in Romania. While the second map [Figure 3] displays non-metal relationships such as similar decorative patterns or shared customs shown in both regions. All these data allow us to analyze how the circulation and stylistic elements of bronze spread along multiple paths in the LBA period with both spatial and network dimensions. The focus is to identify key sites that served as hubs in the exchange network, trace the possible pathways of transmission, and then evaluate how metallurgical distribution could be implicated by geography.

Distribution of Metal Artifacts and Mines

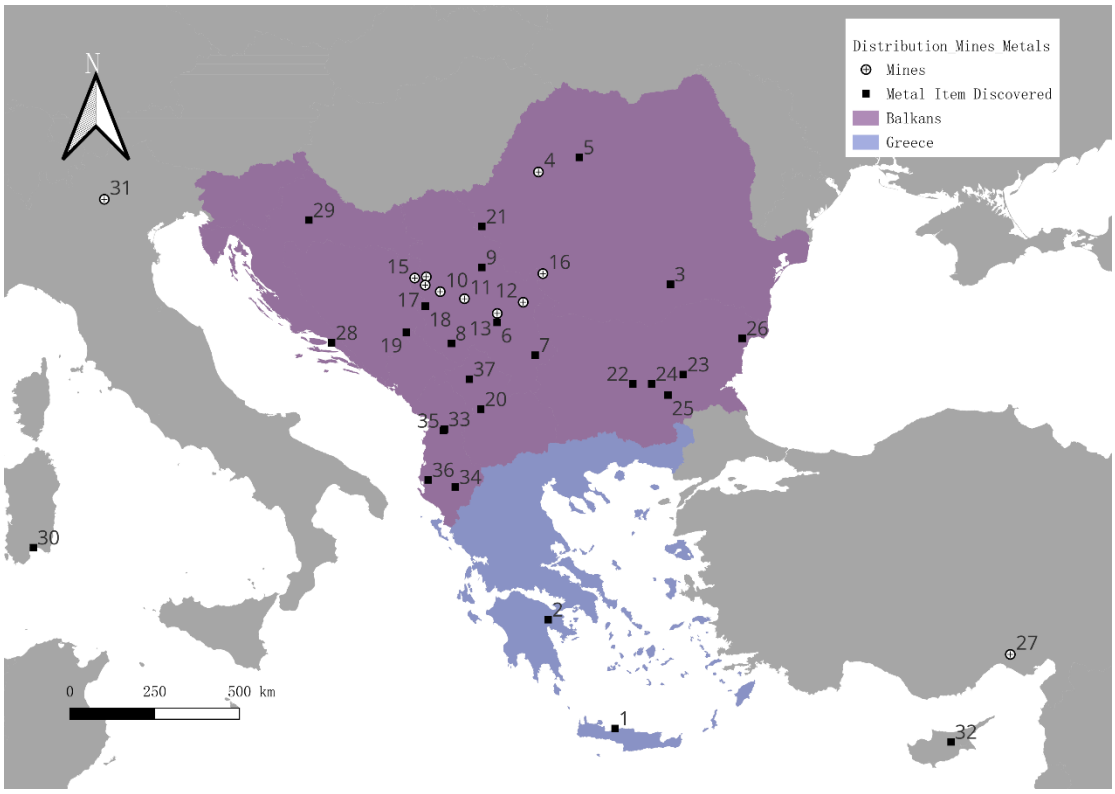

Figure 2: Map of distribution of mines and Mycenaean-style bronze found in the research area. For site IDs and names, please see Table 1.

The distribution map of locations of bronze and mines has been discovered with Mycenaean culture and the central Balkans as the key points will be analyzed from north to south. The analysis begins in the northern and western edges of the Balkans, typically regions that are considered peripheral within the wider exchange system, these include Transylvania, Kloštar Ivanić, and Makarska (SITE5, 29, and 28 in Figure 2, Table 1). In all three of these sites, archaeological records document the discovery of

miniature oxhide ingots, which are unique and characteristic forms during the LBA and dating back to the 12th century BC, although their material source remains unidentified (Sabatini 2016, 35–38). While a direct connection to the Mycenaean world has not been definitively established, several evidence suggest the possibility that these areas were involved in the wider bronze trade network.

Firstly, the dating of the oxhide ingots coincided with the period of intensified interaction between the Balkans and the Aegean in the 12th century BC as indicated before (Bulatovic, Molloy, and Filipovic 2021, 62). This temporal overlap implies that material contact with Mycenaean centers, while not conclusively proven yet, remains plausible. Scholarship has shown that Cyprus gained control over oxhide ingot production sometime in the 14th century BC, since then, nearly all discovered examples of these ingots have been traced back to Cypriot copper sources (Sabatini 2016, 39). This implied that even ingots found in the Balkans likely originated from the eastern Mediterranean. Therefore, these artifacts may be evidence of a bronze trade route that flowed from the southeast to the northwest, regardless of whether it passed directly through the Greek mainland. Moreover, although silver was not part of the bronze resource system, evidence shows that silver from mines of Transylvania had already reached the Mycenaean centers by the 16th century BC (Sabatini 2016, 40; Stos-Gale 2014, 205). This early interaction strengthens the possibility that the northern Balkans had some form of exchange relationship with Mycenaean Greece even prior to the widespread distribution of oxhide ingots.

On the other hand, SITE4 (Apuseni Mountains, Romania) is thought to be one of the few mines in the region for supplying tin to other parts of the Balkans. This site contains Variscan tin ore deposits (Huska et al. 2014, 477) and is located along the potential trade routes linking SITE5 and SITE29, which makes it reasonable to assume that its tin resources may have moved southward through the Balkans toward the Mediterranean, similar to the silver and oxhide ingots. Thus, even in the absence of direct evidence, the possibility that this region contributed to the Mycenaean bronze supply cannot be ignored, and the route of transmission likely passed through central Balkan regions.

Turning to the eastern Balkans, particularly southern Romania and Bulgaria, the area also appears to have played a role in the broader bronze trade network. At SITE22 to SITE26 [Table 1] in Bulgaria, a significant concentration of oxhide ingots with Cypriot copper has been discovered (Sabatini 2016, 38). Based on this distribution, it is reasonable to assume that the eastern Balkans served as a key point for receiving and redistributing resources, linking the Aegean with northern Balkan regions. In this pathway, SITE3 (Wallachia, Romania) stands out due to its unique characteristics since isotopic analyses of bronze artifacts from this site reveal a match with isotopes found in southeastern Serbia (Bulatovic, Molloy, and Filipovic 2021, 67–68). While the precise source remains unknown, this suggests close metallurgical ties between the eastern and central Balkans. Two hypotheses emerge from this pattern: the first proposes that Cypriot metal resources were transported overland through Bulgaria into Romania, thereby connecting with the northern and western Balkan regions as discussed previously and ultimately linking to central areas. This scenario aligns with a previous

study (Bulatovic, Molloy, and Filipovic 2021, 67–68), which suggests that Južna Morava Valley (SITE6) likely engaged in resource exchange networks extending to the east, west, and north. The second hypothesis is that there was a direct interaction between Bulgaria and the central Balkans, facilitating a bidirectional flow of bronze materials. Regarding which way is considered, both scenarios further underscore the importance of the central Balkans within this network.

The central and southern Balkans, including Serbia, Kosovo, and Albania, show particularly dense findings of both mineral resources and Mycenaean-style bronze artifacts. Notably, items found at Južna Morava Valley, Babušnica, Brnjica, and Kličevac-Rastovača hoard (SITE 6 to SITE9 in Table 1) have provided clear evidence of Mycenaean influence. As a key node of material exchange, SITE6 has produced large numbers of double-edged axes of Mycenaean typology. Meanwhile, settlements as SITE7 to SITE9 have revealed swords, arrowheads, and ingots that closely resemble those from mainland Greece (Bouzek 1994, 218; Bulatovic, Molloy, and Filipovic 2021, 67–68; Gavranović et al. 2022, 16). These point to the existence of a stable and long-term material network between this region and the Aegean world.

The interpretation is further supported by discoveries at Jadar Valley, Paležnica hoard, Tetovo, and Banat region, where numerous ingots have been found alongside Mycenaean rapiers and Type C swords dated to the later stage of LH (Bouzek 1994, 218; Bulatovic, Molloy, and Filipovic 2021, 67–68; Gavranović et al. 2022, 16; Huska et al. 2014, 482; Wójcik 2024, 61). These artifacts reflect not only the south-to-north movement of Mycenaean bronze items, but also the stylistic influence evident in local weapon and tool production. Looking further south, particularly at Burrel, Gërmenj, Komsi, Varibop, and Lglarevo, there is a notable increase in the number of mainland Greek Type C swords (Wójcik 2024, 60–65), clearly indicating a pathway of transmission from Mycenaean Greece to the central Balkans.

Sites located nearer to the Greek mainland likely received bronze objects directly through exchange or trade. In contrast, the farther to the north, the artifacts were more likely to be stylistically influenced by Mycenaean culture and manufactured from local or imported metals. Some tin ore sources that may have played a crucial role in this transmission process are located at SITE10 to SITE17, which are mainly in today's Serbia, have long been considered key tin producing areas in the Balkans (Huska et al. 2014) and may have contributed to the production of Mycenaean bronze items. Additionally, SITE13 in the southern Alps (Trentino region) also supplied and became a major source of copper to the western and central Balkans from around 1600 BC (Gavranović et al. 2022, 28). Taken together, these suggest the presence of an extensive and dynamic bronze trade network centered in the central Balkans, which not only facilitated frequent contact with the Greek mainland but also served as an important zone showing diverse cultural influences.

Therefore, based on this map and analysis above, one can hypothesize that during the LBA period, in addition to the well-established maritime trade route (for example, centering on Anatolian sources and Cypriot oxhide ingots, and including Mycenae, Crete, and Sardinia), the Balkans may have represented one of the primary sources of bronze metal for mainland Greece.

Shared Features

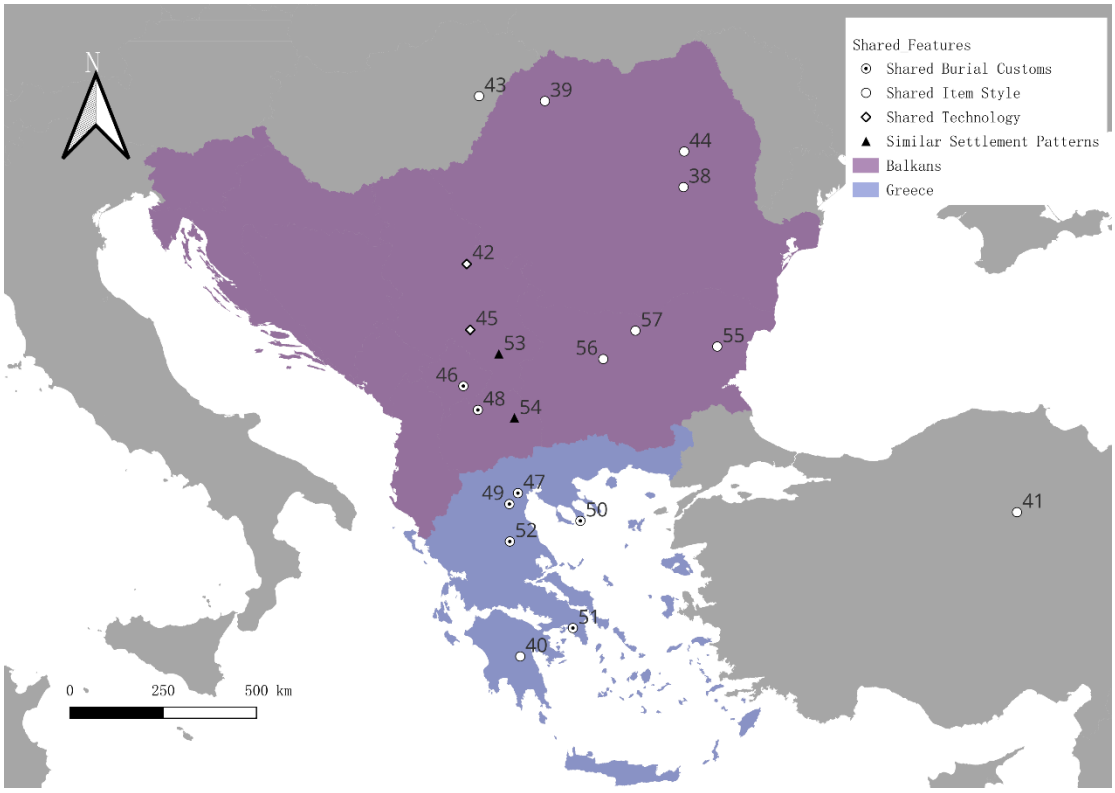

Figure 3: The map of shared features in the Balkans and Mycenaean Greece. For site IDs and names, please see Table 1.

Although the trade network between the Balkan region and the Greek mainland has been primarily reconstructed through the distribution of bronze-related artifacts, much of the discussion has just focused on how the Balkans were influenced by Mycenaean material culture. To deepen this analysis, it is essential to move beyond trade goods and consider cultural expressions more broadly. The following section will therefore explore how mutual cultural influence manifested in decorative styles and mortuary practices and then highlight the parallel development that emerged across both regions.

A particularly revealing category of artifacts that shows the cultural interaction is the set of cheekpieces found across the research region. Four sites, Sărata Monteoru, Oarța de Sus, Grave Circle A at Mycenae, and Alaca Hüyük from Anatolia (SITE38 to 41 in Table 1), have discovered cheekpieces made from different materials that share significant stylistic similarities. At Sărata Monteoru and Oarța de Sus, the excavated bone cheekpieces are characterized by a distinctive two-disc shape with a central hole and a round plate surrounded by three smaller holes (Boroffka 2013, 887; Grigoriev 2021, 166–67). This design closely resembles bronze cheekpieces found in Mycenaean contexts, especially those found in Grave Circle A at Mycenae (Grigoriev 2021, 170), suggesting that there existed either a standardized style or a widely accepted pattern of functional significance within these areas.

These cheekpieces not only displayed the similar shape but also exhibited

decorative motifs such as spiral and wave patterns that are presented on the same items found in Alaca Hüyük from Anatolia. Previous excavations showed that these patterns had already appeared in earlier burial contexts in Anatolia. This observation has led to a proposal about a transmission route that begins in Anatolia, passes through the Balkan region, and then reaches Mycenae (Grigoriev 2021, 173–74). This route is consistent with patterns identified through previous analysis of metal trade.

The spearheads and bone cylinders discovered at Hajdúsámson in Hungary and Costişa in Romania (SITE43 and 44) also reflect the interactions. The Mycenaean spearheads shared a common feature with those found in the Near East and the Carpathian Basin, especially items characterized by an open-socket design (Grigoriev 2021, 177). This morphological similarity suggests not only shared technological innovation but also direct or indirect contact between these geographically distant regions. Therefore, the stylistic commons between Mycenaean spearheads and those found in Eastern Europe support the hypothesis that trade routes passed through the Balkans. In parallel, the discovery of bone cylinders at the Romanian site further strengthens this idea. The object excavated at Costişa shows decorative features that are closely like the Mycenaean style. Chronologically, bone cylinders from Costişa date to around 1700BC, while similar items appear in the archaeological record of Mycenae approximately a century later, around 1600BC (Grigoriev 2021, 173–75). This temporal progression suggests a certain style may have originated in the north and gradually moved southward.

Beyond weaponry and small personal items, ceramic assemblages provide further evidence for sustained cultural interaction across the region. Pottery from sites such as Čerkovna, Plovdiv, and Zimnicea (SITE55 to 57) demonstrates a bidirectional north-south cultural exchange since the ceramic pieces found in Bulgaria and Romania contain incision patterns and elements characteristic of northern Greek pottery traditions (Boroffka 2013). At the same time, potteries like inverted-rim bowls with Balkan style discovered at tombs in Kastanas indicate the mutual influence and integration in burial practices between the two regions (Bulatovic, Molloy, and Filipovic 2021, 70–72, 81–87). This shared ceramic style implies more than simple diffusion from either a Mycenaean cultural center or the Balkans, it reflects an interacted communication in which regional traditions were adapted and localized.

Finally, besides artifacts themselves, parallels in burial forms, technological transmission, and settlement patterns also gain consideration. Previous sections have already examined in detail the contacts within the research areas and supported by several artifactual evidence. This includes, as discussed in earlier research (Bulatovic, Molloy, and Filipovic 2021, 76), the movement of foodstuffs along the Morava Valley into Greece. Accordingly, the following analysis will shift focus toward cultural integration between the Balkans and the Greek mainland to further show the existence of a sustained Bronze Age trade network.

As illustrated in Figure 3, a series of cemeteries and settlements with shared characteristics are distributed across northern Greece and the central and southern regions of the Balkans. These sites suggest a zone of sustained interaction, where technological culture and burial customs reveal notable similarities.

One such example is Dupljaja in Serbia, where a chariot model has been discovered. The design of this model resembles the four-spoked wheel technology found in Mycenaean contexts since the comparable imagery appears on the fresco from Mycenaean tombs, such as those at Tiryns, which show similar structure and function of the chariot (Grigoriev 2021, 171–72). This parallel may indicate a symbol or ritual connection related to elite identity or warrior status between the regions.

The transfer of such practices is further evident in the burials of the Brnjica cultural group in central Balkans. For example, grave goods included globular cups that decorated with spiral motifs, which were widely used in the Balkans, and cremation practices involving the use of urns observed at Balkan sites like Donja Brnjica cemetery are also found at northern Greek sites such as Kastanas (Boroffka 2013, 889; Bulatovic, Molloy, and Filipovic 2021, 65–83; Huska et al. 2014, 482). Additional evidence supporting these connections comes from SITE48, the Klučka cemetery from Skopje in present-day North Macedonia. Some perforated wild boar tusks that are remarkably similar in form and function to components used in Mycenaean helmet production (Bulatovic, Molloy, and Filipovic 2021, 65–87). This type of ornamentation and its presence in both regions shows a shared symbolic culture, which may also be related to the transmission of chariot technology and the representative of elite status.

Taken together, the customs in northern Greece during the LBA period reflect a broader burial pattern seen across the central Balkans. This includes the rise of collective tumuli and a higher frequency of metal objects among grave goods. Vergina, for instance, shows such evident practices in the tombs. In contrast, sites located further south, such as Torone and Kerameikos, display fewer similarities with Balkan traditions. While cemeteries (SITE52, Thessaly) in regions located between these zones appear to exhibit a high degree of cultural diversity and may have functioned as a region where traditions merged or coexisted (Chemsseddoha 2020, 256–65; Wright 2010, 248). This suggests a decrease in direct influence from the northern regions.

Moreover, the fortified hilltop settlements found in the Balkans, like Hisar (SITE53) and Vardarski Rid (SITE54), demonstrated architectural similarities with defensive structures in northern Greece. Given the socio-political instability at many LBA sites, these shared fortification strategies may reflect common responses to threats such as conflicts between communities (Bulatovic, Molloy, and Filipovic 2021, 68, 80–81; Wright 2006, 11).

Altogether, the archaeological record indicates that northern Greece was more heavily influenced by the central and southern regions of the Balkans than the southern Greek mainland. This impact likely extended beyond burial practices to include architecture, symbolic material culture, and pottery styles. One plausible vector for the transmission of these cultural elements was the Morava Valley, a natural north-to-south corridor through which material goods and technological practices could flow into the Greek mainland. Then, this dissemination pathway further supports the idea of a sustained and multidirectional bronze exchange network during the LBA period, while central Balkans played a crucial role in this network not only in terms of bronze resource distribution, but also in facilitating cultural interaction.

Two-Mode Network

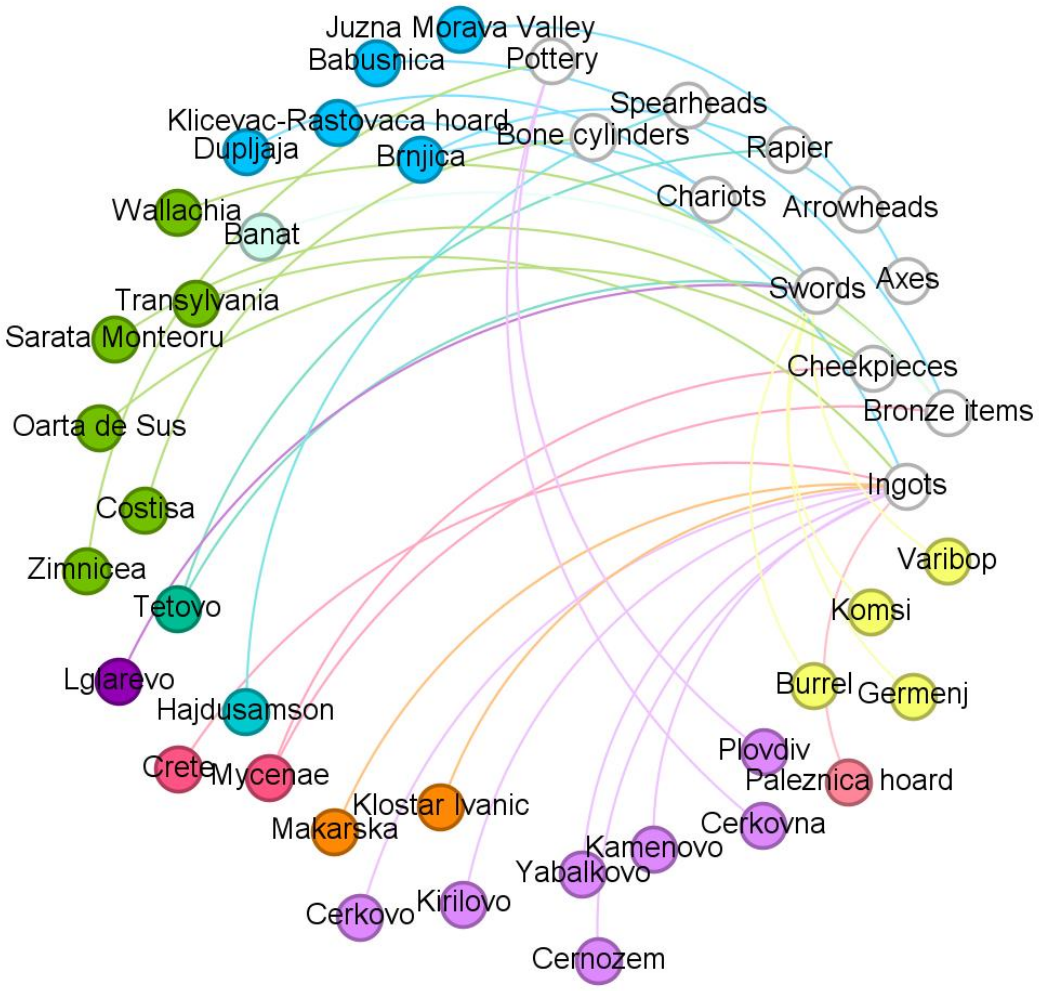

Figure 4: Two-mode network of item-site relationships.

Considering the earlier discussion on the potential representational biases and misinterpretations associated with GIS-based spatial analysis, this section will then employ a two-mode network approach to analyze key artifacts and their frequency across findspots along the trade route. Then ultimately identify potential intermediary hubs and routes that may have facilitated the exchange network. This method aims to provide a complementary perspective on the interaction between the Balkan region and the Greek mainland during the LBA, and to help refine our understanding of the structure of this bronze trade network.

Figure 4 illustrates the network with white nodes on the right representing the categories of objects included in this study, while all other nodes indicate archaeological findspots. Sites from the same geographic region are colored to help visualize regional connections. Edges (such as lines and links) indicate the presence of a specific artifact type at a given site. These connections form the basis for shared

cultural practices or exchange links. This network does not include mines or non-material features like burial customs, rather, it focuses on material culture directly associated with Mycenaean influence, such as bronze artifacts, ornaments, and bronze-related objects. In addition, it includes ingots that are believed to have originated from Cyprus but passed through the study area during circulation. The category labeled “Bronze items” refers to items that either exhibit stylistic characteristics linked to Mycenaean craftsmanship or show clearly documented movement patterns, although not all of them can be classified into established typologies.

In order to better understand the structure of the two-mode network, a set of quantitative metrics was applied [Table 2]. Degree centrality was calculated to identify the number of direct connections between nodes, highlighting artifacts that circulated widely or sites with diverse findings (Brughmans and Peeples 2020, 279). Component IDs were used to detect the subgroups of interconnected sites and objects, which may represent regional interaction (Mills 2017, 382). Modularity analysis identified density within the network links (Blondel et al. 2008, 2), suggesting patterns of stylistic similarity or localized trade. Then the eigenvector centrality was calculated to evaluate the importance of nodes, identifying nodes that are influential not just due to the quantity of connections, but also because of the link with other important nodes (Bonacich 2007, 555). By taking these together, these metrics help to reveal both the structural and cultural significance of specific sites and artifacts in the exchange network.

Among all object categories analyzed, bronze ingots emerge as the most widely distributed and frequently recorded material due to the highest degree and eigenvector centrality shown in the statistical result. These ingots, whether definitively sourced from Cyprus or not, account for approximately 32% of all object samples included in the dataset. Their findspots are geographically diverse, spanning from Serbia and Romania in the north to Greece, Croatia, Bulgaria, and Bosnia in the south and southeast (Gavranović et al. 2022; Sabatini 2016). The highest concentration of ingots appears in Bulgaria, where a pattern that suggests its position as both a recipient and possible redistributor of bronze resources. As the frequency of ingot finds reduces further north, especially in areas such as Romania, it could be reinforced that the southeastern Balkan region as a critical corridor for the dissemination of materials during the LBA. This supports the hypothesis that the region in Bulgaria, due to its location, functioned as a key intermediary zone within the broader metal exchange network.

The second most frequently occurring object type is Mycenaean-style swords, which make up roughly 20.5% of the total sample and with the second highest degree and eigenvector centrality. These swords have been uncovered in a range of locations, including Serbia, Romania, Kosovo, North Macedonia, and Albania (Bulatovic, Molloy, and Filipovic 2021; Gavranović et al. 2022; Wójcik 2024). Their concentration becomes noticeably higher in the southern part of the Balkans, closer to the Greek mainland. This pattern implies a gradual diffusion of Mycenaean martial technology and supports the idea that military-related items were not only symbolic but also mobile within

these trade systems. The direction of sword distribution from the southern Balkans into central and northern regions, parallel to the known pathways of resource movement as discussed. Specifically, areas in Romania and Serbia are rich in tin ore (Huska et al. 2014), the presence of Mycenaean-style swords in such zones suggests that exchange may have been reciprocal, with raw materials moving southward, and objects moving northward. This indicates not just simple one-directional trade, but a complex system of mutual interaction and goods exchange that included both practical tools and symbolic items.

Therefore, among the artifact types, bronze ingots stand out with the highest degree (11) and eigenvector centrality (1.0), showing their wide distribution and fundamental role in regional exchange. Swords follow with a degree of 7 and eigenvector centrality of 0.366, indicating the circulation of martial items possibly associated with elite display or warfare. Most sites and artifacts exhibit a lower degree or eigenvector centrality, which may highlight limited associations of types and localized connections with regional hubs, suggesting a multi-nodal system within this exchange network.

The component structure indicates that the network is partially fragmented, since the 8 subgroups reflect the independent but occasionally interconnected exchange routes. Regions like the central Balkans form relatively cohesive clusters, while sites further north or west remain more isolated in the network.

This system structure also be shown by the modularity analysis, which produced 8 distinct community clusters, with the largest clusters (Class 1 and 3) covering key sites across Bulgaria, Serbia, and Romania. These regions are not only rich in terms of object count but also in the variety of Mycenaean-related items. Particularly in the central Balkan region, such as Serbia, shows a density of materials connected to Mycenaean culture. Excavations have uncovered arrowheads, axes, swords, and even components related to chariot technology (Bulatovic, Molloy, and Filipovic 2021; Gavranović et al. 2022; Huska et al. 2014). This complexity points to a deep and possibly sustained interaction between Mycenaean and central Balkan communities. Rather than passive recipients of goods, these areas may have been active participants in the adoption of Mycenaean cultural elements.

From a network perspective, this makes the central Balkans a region of high centrality, not just geographically but functionally within the LBA exchange system. This interaction likely took place within multifunctional contexts involving warfare, prestige display, and ritual activity. The frequency of Mycenaean weapons and warfare-associated artifacts in these regions aligns with broader interpretations of the Mycenaean world as a society with martial and hierarchical status (French 2012, 674; Wright 2010, 247–48). Thus, the spread of swords, spearheads, and chariot technology could be interpreted as part of the cultural strategy aimed at expressing power among elite groups within these regions.

These findings also have implications for understanding the broader sociopolitical landscape of the LBA Aegean world. The collapse of the major palatial centers in the Mycenaean world, and the widespread disruption throughout the eastern Mediterranean around 1200BC, has often been interpreted as a period of systemic

breakdown (French 2012, 676). The patterns observed in the network suggest that increased interaction and possibly common defense strategies may have formed in response to these growing instabilities. The dissemination of Mycenaean-style weapons and military technology may thus represent more than trade, but reflect efforts to reinforce social and political alliances, or shared responses to external pressures such as conflicts among communities.

It is also important to consider the role of intermediary settlements and nodes in facilitating this network. Regions such as North Macedonia and Kosovo might have functioned as cultural and material bridges between the resource-rich north and the Mycenaean sites. Their strategic position enabled the flow of both raw materials and cultural influence and then consolidated their role in this mutual system of exchange.

In conclusion, the two-mode network analysis reveals that the central and southeastern Balkans played a crucial role in the movement of bronze and Mycenaean-related objects. The prominence of ingots and weapons, combined with their widespread distribution and association with high hierarchical status contexts, underscores the importance of martial and metallurgical exchange in this network. Therefore, the Mycenaean-Balkan relationship during the LBA period was active, reciprocal, and in broader socioeconomic dynamics.

Heatmap

Finally, a kernel density heatmap was generated by including all the collected sites with evidence of metal artifacts or characteristic culture related to the research topic. Kernel Density Estimation is a spatial analysis technique that calculates the density of point features within a defined area, effectively highlighting zones of high intensity of archaeological activity (Conolly and Lake 2006; QGIS Documentation, n.d.). This method was chosen because it reveals spatial trends more clearly than point maps, especially when interpreting uneven site distribution. The resulting heatmap [Figure 5] based on this technique highlights the major zones of spatial concentration of relevant sites: the central Balkans, particularly present-day Serbia, and the southeastern Balkans such as Bulgaria. The darker red areas indicate zones with a higher density of relevant sites, suggesting intensified activity of metallurgy-related cultural exchange.

These zones correspond closely with the previous discussion, especially the central and southeastern Balkan as the key intermediary zones that may connect northern ore sources with southern consumption centers. Its overlap with multiple documented trade corridors supports the hypothesis that these regions functioned as hubs within the network.

This spatial visualization confirms the results of the two-mode network analysis, which identified these same regions as high-connectivity nodes. Furthermore, the heatmap visually demonstrates the uneven spatial intensity of metallurgical activity, suggesting the idea of a modular exchange system rather than a uniformly distributed network.

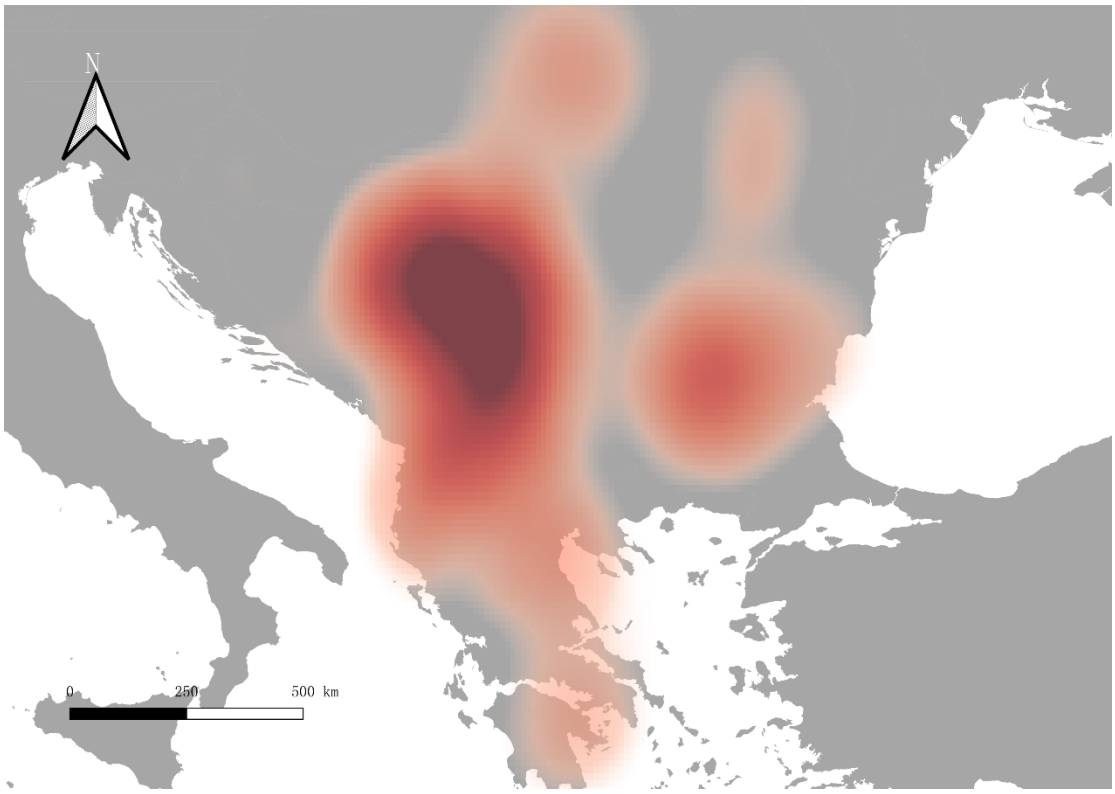

Figure 5: The kernel density heatmap of all relevant sites included in this research.

Discussion of the Outcome

Through the combined application of GIS-based spatial analysis and two-mode social network analysis, this study provides an interpretation of the interregional dynamics that shaped the circulation of bronze and Mycenaean-style artifacts during the LBA period. The central Balkans emerged as the most consistent area of contact and transformation, receiving materials from the north (possibly from tin and copper sources in modern-day Romania and Italy) and redistributing both raw materials and worked items southward toward the Aegean. The outcome of this study allows us to construct a hypothesized model of the LBA bronze trade network between Mycenaean Greece and the Balkans [Figure 6].

This visualization suggests a directional exchange route, with Mycenaean Greece functioning as a terminal consumption point and the central Balkans acting as a pivotal zone of resource redistribution. The model reflects both the spatial patterns detected through GIS mapping and the relational structures revealed by two-mode network analysis, particularly emphasizing the importance of intermediary zones such as Bulgaria and Serbia.

Meanwhile, the high frequency of Mycenaean-style weapons in the central and southern Balkans suggests a deliberate adoption of martial prestige items by local elites, possibly as a form of political contact or alliance-making with Mycenaean settlements. These insights emerge a multi-nodal system characterized by bidirectional exchange and mutual adaptation of foreign objects within local

sociopolitical contexts.

Thus, this route model contributes to the ongoing debate on LBA metal circulation by proposing a multi-nodal, bidirectional network that highlights the central Balkans as a critical intermediate between the northern metal sources and southern consumption centers like Mycenaean Greece. Unlike earlier models that emphasize Aegean-centered maritime trade, this visualization integrates both north-south overland movement, maritime pathways originating from Cyprus or the Near East, and the mixed transport paths involving both maritime and terrestrial segments. This model reframes the Balkans not only as a transit zone but also as a transformation and distribution center in a modular, bidirectional system of exchange.

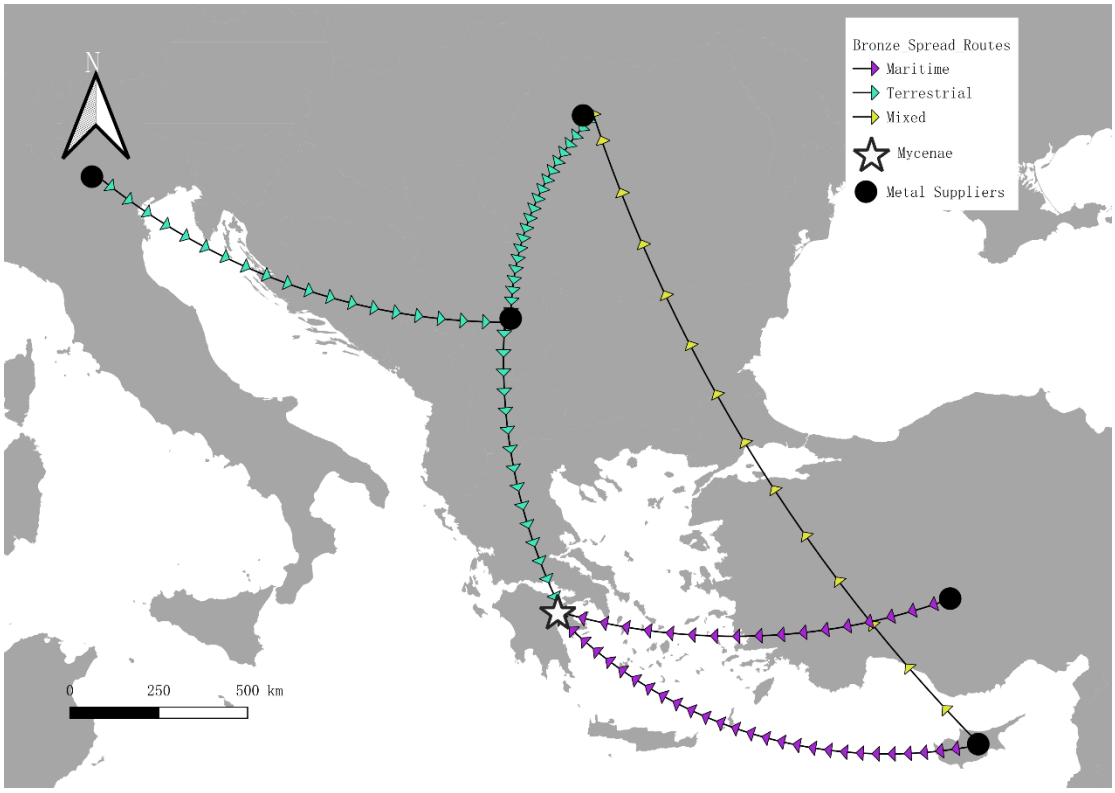

Figure 6: Map of the hypothetical trade routes proposed in this paper.

Limitations and Challenges

The methodological framework employed in this project offers a sustainable and replicable model for future archaeological investigations. This approach is dynamic and adaptable to new data inputs. As more excavation reports are digitized and integrated into open-access platforms, the underlying dataset could be easily expanded, allowing researchers to test, refine, or even challenge the proposed model.

Moreover, the relational logic of the network analysis shows a more inclusive understanding of connectivity that is not bound by geopolitical borders or traditional culture-area framework. This makes the method particularly useful for regions like the Balkans, where cultural identities in prehistory were fluid and overlapping. In this case,

the sustainability of the research lies not only in its methodology but also in its ability to accommodate complexity and ambiguity.

Despite the contribution of the project, it is also necessary to consider the limitations. One of the most significant challenges encountered was the uneven quality or quantity of data across different regions. Although some areas, such as Serbia and Bulgaria, are relatively well-documented in terms of both excavation volume and publication detail, other regions, particularly those lying in the western and northern Balkans, remain underrepresented in the dataset. This imbalance may lead to the ambiguity and misunderstanding of the network centrality calculations, for example, the apparent absence of bronze-related items in certain regions may reflect a lack of excavation or publication rather than actual trade disconnection.

Furthermore, the classification of Mycenaean-style objects presents interpretive challenges. Without detailed typological or metallurgical studies for each findspot, it remains difficult to draw definitive conclusions about the origin or symbolic function of individual artifacts. Similarly, the category of "ingots" remains broad and sometimes ambiguous, especially in cases where their provenance is assumed rather than confirmed through compositional analysis.

Additionally, the LBA spans several centuries and includes multiple phases of social and political transformation (Manning 2012), including the collapse of the Mycenaean palatial system. The network presented in this research project shows a temporal amalgamation, which may lead to the overlooking of significant chronological shifts in trade intensity, object function, or regional connectivity.

To address these limitations, future research should consider systematic data collection and standardization across broader regions. This includes improving access to excavation data from underrepresented areas among the Balkans and Greece and promoting the digitization of literature and excavation reports. These may enhance both the precision and scope of the spatial and network analyses. Another key direction involves the integration of scientific analyses such as isotopic sourcing and metallurgical studies. By directly tracing the geological origins of tin and copper components, the hypothesis about trade routes and regional production could be tested more accurately.

Finally, other digital tools such as 3D modeling and animation may offer accessible platforms for the visualization of trade routes and production evolution. These tools could reconstruct not just active and static trade paths but also help to visualize how networks shifted with sociopolitical changes. This would be valuable in demonstrating the possible relationship between material exchange and historical processes, such as collapse and reorganization in the LBA period.

Conclusions

In general, this study demonstrates the effectiveness of integrating spatial and network-based approaches to reconstruct prehistoric trade and interaction systems. By focusing on the movement of bronze objects and Mycenaean-style artifacts across

the Balkan region, with the diffusion of cultural traditions, this project proposes a LBA interaction model centered on the exchange of metal resources.

In this model, the central Balkans functioned as a key intermediary that highlights the importance of local communities in shaping long-term networks. Moreover, the stylistic characteristics of the circulating artifacts offer insight into the sociopolitical transformation occurring between the Balkans and mainland Greece during the period.

While the methodology employed in this research is sustainable and adaptable, the study also identifies several areas that require further data, critical reevaluation, and technological refinement. The complexity of LBA connectivity needs to be continuously investigated, not only to enhance the understanding of ancient economic and political developments, but also to support more inclusive and diverse interpretations of prehistoric Europe.

Tables

ID	Site_Name	Country	Note
1	Crete	Greece	Metal Item Discovered
2	Mycenae	Greece	Metal Item Discovered
3	Wallachia	Romania	Metal Item Discovered
4	Apuseni Mountains	Romania	Mines
5	Transylvania	Romania	Metal Item Discovered
6	Juzna Morava Valley	Serbia	Metal Item Discovered
7	Babusnica	Serbia	Metal Item Discovered
8	Brnjica	Serbia	Metal Item Discovered
9	Klicevac-Rastovaca hoard	Serbia	Metal Item Discovered
10	Valjevo	Serbia	Mines
11	Rudnik	Serbia	Mines
12	Bor	Serbia	Mines
13	Paracin	Serbia	Mines
14	Tekeris	Serbia	Mines
15	Loznica	Serbia	Mines
16	Bela Crkva	Serbia	Mines
17	Cer	Serbia	Mines
18	Jadar Valley	Serbia	Metal Item Discovered
19	Paleznica hoard	Bosnia	Metal Item Discovered
20	Tetovo	North Macedonia	Metal Item Discovered
21	Banat	Romania/Serbia/Hungary	Metal Item Discovered
22	Cerkovo	Bulgaria	Metal Item Discovered
23	Kirilovo	Bulgaria	Metal Item Discovered
24	Cernozem	Bulgaria	Metal Item Discovered
25	Yabalkovo	Bulgaria	Metal Item Discovered
26	Kamenovo	Bulgaria	Metal Item Discovered
27	Taurus Mountains	Turkey	Mines
28	Makarska	Croatia	Metal Item Discovered
29	Klostar Ivanic	Croatia	Metal Item Discovered
30	Sardinia	Italy	Metal Item Discovered
31	Southern Alps	Italy	Mines
32	Cyprus	Cyprus	Metal Item Discovered
33	Burrel	Albania	Metal Item Discovered
34	Germenj	Albania	Metal Item Discovered
35	Komsi	Albania	Metal Item Discovered
36	Varibop	Albania	Metal Item Discovered
37	Lglarevo	Kosovo	Metal Item Discovered
38	Sarata Monteoru	Romania	Shared Item Style
39	Oarta de Sus	Romania	Shared Item Style
40	Grave Circle A	Greece	Shared Item Style
41	Alaca Huyuk	Turkey	Shared Item Style
42	Dupljaja	Serbia	Shared Technology
43	Hajdusamson	Hungary	Shared Item Style
44	Costisa	Romania	Shared Item Style
45	Morava valley	Serbia	Shared Technology
46	Donja Brnjica	Serbia	Shared Burial Customs
47	Kastanas	Greece	Shared Burial Customs
48	Klucka cemetery	North Macedonia	Shared Burial Customs
49	Vergina	Greece	Shared Burial Customs
50	Torone	Greece	Shared Burial Customs
51	Kerameikos	Greece	Shared Burial Customs
52	Thessaly	Greece	Shared Burial Customs
53	Hisar Hill	Serbia	Similar Settlement Patterns
54	Vardarski Rid	North Macedonia	Similar Settlement Patterns
55	Cerkovna	Bulgaria	Shared Item Style
56	Plovdiv	Bulgaria	Shared Item Style
57	Zimnicea	Romania	Shared Item Style

Table 1: Site IDs and names on the GIS map.

Label	Type	Country	Degree	Component ID	Modularity Class	Eigenvector Centrality
Arrowheads	item		1	3	3	0.059922468
Axes	item		1	2	0	0.009984517
Bone cylinders	item		1	6	6	0.009984517
Bronze items	item		4	1	2	0.122995072
Chariots	item		1	4	4	0.009984517
Cheekpieces	item		3	1	2	0.086527822
Ingots	item		11	0	1	1
Pottery	item		3	7	7	0.055656918
Rapier	item		1	3	3	0.059922468
Spearheads	item		1	5	5	0.009984517
Swords	item		7	3	3	0.366166435
Babusnica	site	Serbia	1	1	2	0.056209766
Banat	site	Romania/Serbia/Hungary	1	1	2	0.056209766
Brnjica	site	Serbia	2	3	3	0.159133921
Burrel	site	Albania	1	3	3	0.134432417
Cerkovna	site	Bulgaria	1	7	7	0.03188311
Cerkovo	site	Bulgaria	1	0	1	0.301416938
Cernozem	site	Bulgaria	1	0	1	0.301416938
Costisa	site	Romania	1	6	6	0.009984517
Crete	site	Greece	1	0	1	0.301416938
Dupljaja	site	Serbia	1	4	4	0.009984517
Germenj	site	Albania	1	3	3	0.134432417
Hajdusamson	site	Hungary	1	5	5	0.009984517
Juzna Morava Valley	site	Serbia	1	2	0	0.009984517
Kamenovo	site	Bulgaria	1	0	1	0.301416938
Kirilovo	site	Bulgaria	1	0	1	0.301416938
Klicevac-Rastovaca hoard	site	Serbia	1	0	1	0.301416938
Klostar Ivanic	site	Croatia	1	0	1	0.301416938
Komsi	site	Albania	1	3	3	0.134432417
Lglarevo	site	Kosovo	1	3	3	0.134432417
Makarska	site	Croatia	1	0	1	0.301416938
Mycenae	site	Greece	2	1	2	0.097778302
Oarta de Sus	site	Romania	1	1	2	0.041568536
Paleznica hoard	site	Bosnia	1	0	1	0.301416938
Plovdiv	site	Bulgaria	1	7	7	0.03188311
Sarata Monteoru	site	Romania	1	1	2	0.041568536
Tetovo	site	North Macedonia	2	3	3	0.159133921
Transylvania	site	Romania	1	0	1	0.301416938
Varibop	site	Albania	1	3	3	0.134432417
Wallachia	site	Romania	1	1	2	0.056209766
Yabalkovo	site	Bulgaria	1	0	1	0.301416938
Zimnicea	site	Romania	1	7	7	0.03188311

Table 2: Statistical results of the two-mode network.

Bibliography

Aulsebrook, Stephanie Jane. 2020. “Understanding the Role of Metal within the Late Bronze Age Community at Mycenae: Challenges and Potential Approaches.” *Polish Archaeology in the Mediterranean*, no. 29/2 (December), 237–64. https://doi.org/10.31338/uw.2083-537X.pam29.2.10.

Blackwell, Nicholas G. 2018. “Contextualizing Mycenaean Hoards: Metal Control on the Greek Mainland at the End of the Bronze Age.” *American Journal of Archaeology* 122 (4): 509–39. https://doi.org/10.3764/aja.122.4.0509.

Blondel, Vincent D, Jean-Loup Guillaume, Renaud Lambiotte, and Etienne Lefebvre. 2008. “Fast Unfolding of Communities in Large Networks.” *Journal of Statistical Mechanics: Theory and Experiment* 2008 (10): P10008. https://doi.org/10.1088/1742-5468/2008/10/P10008.

Bonacich, Phillip. 2007. “Some Unique Properties of Eigenvector Centrality.” *Social Networks* 29 (4): 555–64. https://doi.org/10.1016/j.socnet.2007.04.002.

Boroffka, Nikolaus. 2013. *Romania, Moldova, and Bulgaria*. The Oxford Handbook of the European Bronze Age. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199572861.013.0047.

Bouzek, J. 1994. “Late Bronze Age Greece and the Balkans: A Review of the Present Picture.” *The Annual of the British School at Athens* 89 (November):217–34. https://doi.org/10.1017/S0068245400015380.

Brughmans, Tom, and Matthew A. Peeples. 2020. “Spatial Networks.” In *Archaeological Spatial Analysis*, 273–95. London: Routledge. https://doi-org.proxy.uba.uva.nl/10.4324/9781351243858.

Bulatovic, Aleksandar, Barry Molloy, and Vojislav Filipovic. 2021. “The Balkan-Aegean Migrations Revisited: Changes in Material Culture and Settlement Patterns in the Late Bronze Age Central Balkans in Light of New Data.” *Starinar*, no. 71, 61–105. https://doi.org/10.2298/STA2171061B.

Chemsseddoha, Anne-Zahra. 2020. *Spheres of Interaction: Contacts and Relationships between the Balkans and Adjacent Regions in the Late Bronze Proceedings of the Conference Held at the Institute of Archaeology, Belgrade, 15-17 September, 2017*. Perspectives on Balkan Archaeology, volume 1. Rahden/ Westf: VML, Verlag Marie Leidorf GmbH.

Conolly, James, and Mark Lake. 2006. “SPATIAL ANALYSIS.” In *Geographical Information Systems in Archaeology*, 1st ed. Cambridge University Press. https://doi.org/10.1017/CBO9780511807459.

Day, Peter M., and Roger C. P. Doonan. 2007. *Metallurgy in the Early Bronze Age Aegean: Lame Excuses for Emerging Complexity in Early Bronze Age Crete: The Metallurgical Finds from Poros Katsambas and Their Context*. Sheffield Studies in Aegean Archaeology 7. Oxford: Oxbow books.

French, Elizabeth. 2012. “Mycenae.” In *The Oxford Handbook of the Bronze Age Aegean*, edited by Eric H. Cline, 671–79. Oxford New York: Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199873609.013.0050.

Gavranović, Mario, Mathias Mehofer, Aleksandar Kapuran, Jovan Koledin, Jovan Mitrović, Aleksandra Papazovska, Andrijana Pravidur, Aca Đorđević, and Dragan Jacanović. 2022. “Emergence of Monopoly–Copper Exchange Networks during the Late Bronze Age in the Western and Central Balkans.” Edited by Peter F. Biehl. *PLOS ONE* 17 (3). https://doi.org/10.1371/journal.pone.0263823.

Grigoriev, Stanislav. 2021. “THE EVOLUTION OF ANTLER AND BONE CHEEKPIECES FROM THE BALKAN-CARPATHIAN REGION TO CENTRAL KAZAKHSTAN: CHRONOLOGY OF ‘CHARIOT’ CULTURES AND MYCENAEAN GREECE.” *JOURNAL OF ANCIENT HISTORY AND ARCHAEOLOGY* 8 (2): 148–89. https://doi.org/10.14795/j.v8i2.633.

Guidi, Gabriele, Michele Russo, and Davide Angheleddu. 2014. “3D Survey and Virtual Reconstruction of Archeological Sites.” *Digital Applications in Archaeology and Cultural Heritage* 1 (2): 55–69. https://doi.org/10.1016/j.daach.2014.01.001.

Huska, A., W. Powell, S. Mitrović, H. A. Bankoff, A. Bulatović, V. Filipović, and R. Boger. 2014. “Placer Tin Ores from Mt. Cer, West Serbia, and Their Potential Exploitation during the Bronze Age.” *Geoarchaeology* 29 (6): 477–93. https://doi.org/10.1002/gea.21488.

Iacono, Francesco, Elisabetta Borgna, Maurizio Cattani, Claudio Cavazzuti, Helen

Dawson, Yannis Galanakis, Maja Gori, et al. 2021. “Establishing the Middle Sea: The Late Bronze Age of Mediterranean Europe (1700–900 BC).” *Journal of Archaeological Research* 30 (3): 371–445. https://doi.org/10.1007/s10814-021-09165-1.

Lock, Gary, and John Pouncett. 2017. “Spatial Thinking in Archaeology: Is GIS the Answer?” *Journal of Archaeological Science* 84 (August):129–35. https://doi.org/10.1016/j.jas.2017.06.002.

Manning, Sturt W. 2012. “Chronology and Terminology.” In *The Oxford Handbook of the Bronze Age Aegean*, edited by Erin M. Cline, 1st ed., 11–28. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199873609.013.0002.

Michael, Dimitra Ermioni, Linda Fibiger, Ioanna Moutafi, Mario Šlaus, Maria Katsimicha, Mario Novak, and Barry Molloy. 2023. “Exploring Connectivity in Late Bronze Age/Early Iron Age Greece and the Balkans Using Cranial Non-Metric Analysis.” *Archaeological and Anthropological Sciences* 15 (11): 165. https://doi.org/10.1007/s12520-023-01862-w.

Mills, Barbara J. 2017. “Social Network Analysis in Archaeology.” *Annual Review of Anthropology* 46:379–97.

Morgan, Colleen, and Stuart Eve. 2012. “DIY and Digital Archaeology: What Are You Doing to Participate?” *World Archaeology* 44 (4): 521–37. https://doi.org/10.1080/00438243.2012.741810.

Muhly, James D. 1985. “Sources of Tin and the Beginnings of Bronze Metallurgy.” *American Journal of Archaeology* 89 (2): 275–91. https://doi.org/10.2307/504330.

Papadimitriou, George. 2024. “Aegean Metallurgy in the Bronze Age: The Technological Evolution of Copper Alloys in the Aegean during the Prehistoric Period.” *Aegean Metallurgy in the Bronze Age*, November, 271–87.

QGIS Documentation. n.d. “24.1.6.1. Heatmap (Kernel Density Estimation).” QGIS User Guide. Accessed June 26, 2025. https://docs.qgis.org/3.40/en/docs/user_manual/processing_algs/qgis/interpolation.html#heatmap-kernel-density-estimation.

Radivojević, Miljana, and Benjamin W. Roberts. 2021. “Early Balkan Metallurgy: Origins, Evolution and Society, 6200–3700 BC.” *Journal of World Prehistory* 34 (2): 195–278. https://doi.org/10.1007/s10963-021-09155-7.

Runfola, Daniel, Austin Anderson, Heather Baier, Matt Crittenden, Elizabeth Dowker, Sydney Fuhrig, Seth Goodman, et al. 2020. “geoBoundaries: A Global Database of Political Administrative Boundaries.” *PLOS ONE* 15 (4): e0231866. https://doi.org/10.1371/journal.pone.0231866.

Sabatini, Serena. 2016. “LATE BRONZE AGE OXHIDE AND OXHIDE-LIKE INGOTS FROM AREAS OTHER THAN THE MEDITERRANEAN: PROBLEMS AND CHALLENGES.” *Oxford Journal of Archaeology* 35 (1): 29–45. https://doi.org/10.1111/ojoa.12077.

Şahoğlu, Vasif. 2005. “THE ANATOLIAN TRADE NETWORK AND THE IZMIR REGION DURING THE EARLY BRONZE AGE.” *Oxford Journal of Archaeology* 24 (4): 339–61. https://doi.org/10.1111/j.1468-0092.2005.00240.x.

Stos-Gale, Zofia. 2014. “Silver Vessels in the Mycenaean Shaft Graves and Their Origin in the Context of Metal Supply in the Bronze Age Aegean.” *Tagungen Des Landesmuseums Für Vorgeschichte Halle* 11:183–207.

Thrift, Nigel. 1996. *‘Strange Country’: Meaning, Use and Style in Non Representational Theories*. Spatial Formations. 1 Oliver’s Yard, 55 City Road, London EC1Y 1SP United Kingdom: SAGE Publications Ltd. https://doi.org/10.4135/9781446222362.

Tzachili, Iris. 2004. “Aegean Metallurgy in the Bronze Age: Recent Developments.” *Aegean Metallurgy in the Bronze Age*, November, 7–33.

Wace, A. J. B. 1957. “Mycenae 1939-1956, 1957: Part V. The Chronology of Late Helladic IIIB.” *The Annual of the British School at Athens* 52:220–23.

Wójcik, Jarosław. 2024. “Distribution of Middle and Late Bronze Age Swords and Daggers with Aegean Analogies in Northern Greece, Albania, North Macedonia, Kosovo and Serbia.” *Slovenská Archeológia* 72 (1): 57–80. https://doi.org/10.31577/slovarch.2024.72.3.

Wright, James C. 2006. “THE FORMATION OF THE MYCENAEAN PALACE.” In *Ancient Greece*, by Sigrid Deger-Jalkotzy and Irene Lemos, 7–52. Edinburgh University Press. https://doi.org/10.1515/9780748627295-004.

Wright, James Clinton. 2010. “Early Mycenaean Greece.” In *The Cambridge Companion to the Aegean Bronze Age*, edited by Cynthia W. Shelmerdine, 1st ed., 230–57. Cambridge University Press. https://doi.org/10.1017/CCOL9780521814447.011.