Rough Sets Based Spatial Analysis for Metal Production Area at Mount Nif

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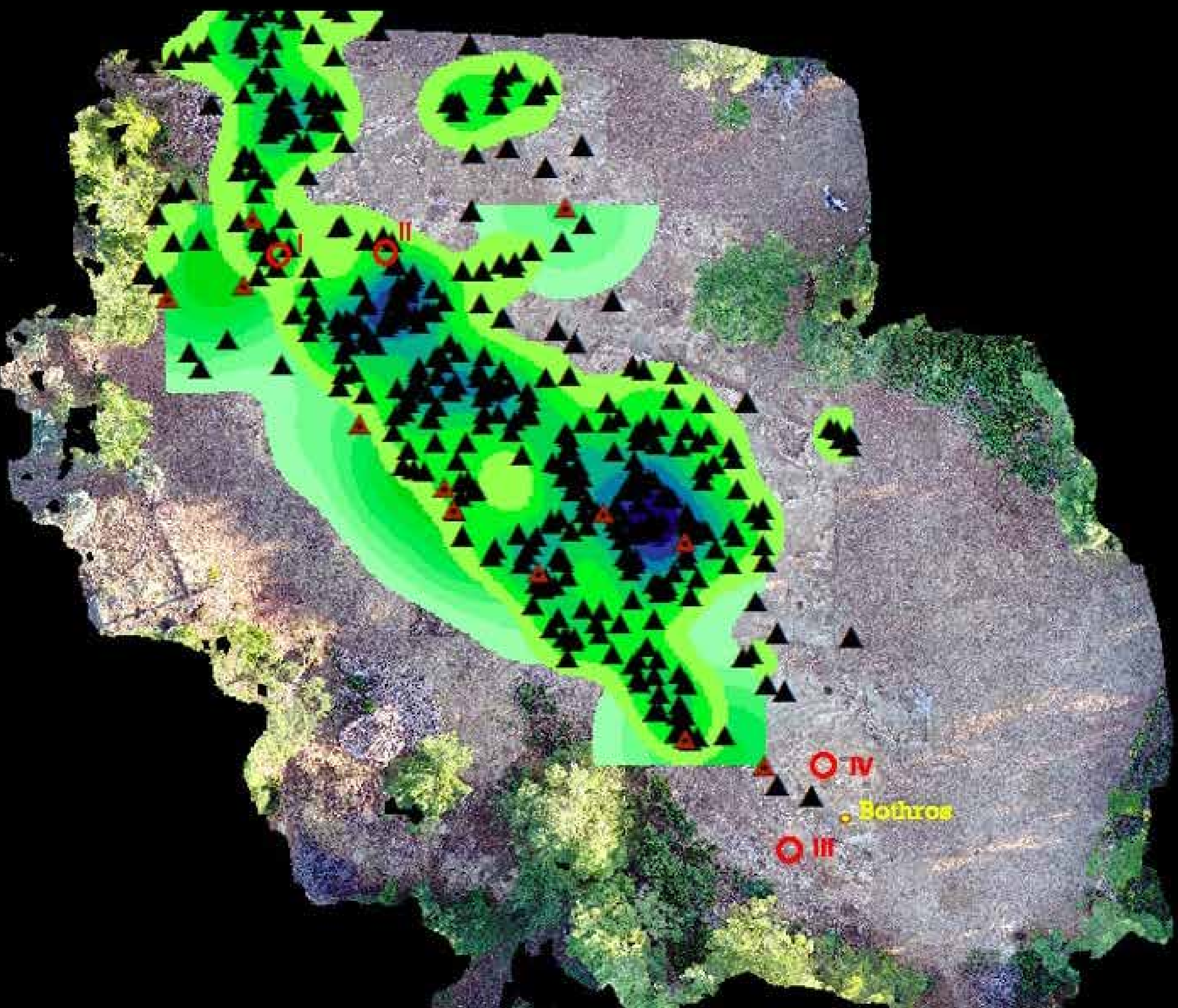
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Araştırma Makalesi

Rough Sets Based Spatial Analysis for Metal Production Area at Mount Nif*[1]

Nif Dağı Metal Üretim Alanının Kaba Küme Temelli Mekansal Analizi

Tutku TUNCALI YAMAN**

Abstract

The Mount Nif (Olympus) Excavation has four excavation areas where southeast of Mount Nif, located in the east of Izmir, Turkey. A significant spot of the project is Karamattepe, defined as a metal production area in the Archaic Period, which is prominent with rich metal finds such as nearly 500 pieces of iron and bronze arrowheads, metal production furnaces, and slags. Albeit mentioned context seems suitable to spatial analysis, per contra, the area which has a natural incline in the north-south axis, had even been used as agricultural land for approximately 100 years in the modern period. As known, both natural slope and agricultural practices such as plowing and spudding in archaeological sites cause translocation, especially in small finds. Under these circumstances, the context does not seem suitable for spatial analysis with deterministic methods. The goal of the study is to understand the specs of the metal production area at Karamattepe by spatial analysis. Studied data include geolocations of arrowheads that are obtained from GIS, their Euclidean distances to the furnaces, various metrics (weight, length, i.e.), and analogical typology as inputs. With the proposed Rough Sets-based approach, the relations metal finds and production points was determined. It is thought that this study will shed light on the researchers to cope out multi-dimensional uncertainties for spatial analysis in landscape archaeology.

Keywords: Rough Sets, Spatial Analysis, Metal Production, Arrowheads, Nif.

Özet

Nif (Olympos) Dağı Kazısı, İzmir'in doğusundaki Nif Dağı'nın güneydoğusunda yer alan dört farklı kazı alanına sahiptir. Projenin önemli bir sahası, Arkaik Dönem'e ait bir metal üretim alanı olarak tanımlanan ve 500'e yakın demir ve bronz ok ucu, metal üretim fırınları ve cüruf gibi zengin buluntularıyla öne çıkan Karamattepe'dir. Söz konusu bağlam her ne kadar mekânsal analize uygun görünse de aksine, kuzey-güney ekseninde doğal bir eğime sahip olan alan, modern dönemde yaklaşık 100 yıl boyunca tarım arazisi olarak bile kullanılmıştır. Bilindiği gibi hem doğal eğim hem de arkeolojik alanlarda gerçekleştirilen tarımsal uygulamalar özellikle küçük buluntuların yer değiştirmesine neden olmaktadır. Bu koşullar altında bağlam, deterministik yöntemler kullanılarak yapılacak mekansal analiz için uygun görünmemektedir. Bu çalışmanın amacı, Karamattepe'deki metal üretiminin özelliklerini mekansal bir analiz ile anlamaktır. Çalışılan veriler, CBS'den elde edilen ok uçlarının coğrafi konumlarını, alanda tespit edilen fırınlara Öklid mesafelerini, (ağırlık, uzunluk, v.b.) çeşitli metrikleri ve ok uçlarının analog tipolojisini içermektedir. Önerilen kaba küme teorisi temelli yaklaşımla metal buluntular ile üretim noktaları arasındaki ilişki belirlenmiştir. Bu çalışmanın, yerleşim arkeolojisinde mekansal analiz için çok boyutlu belirsizliklerin üstesinden gelmek için araştırmacılara ışık tutacağı düşünülmektedir.

Anahtar kelimeler: Kaba Kümeler, Mekansal Analiz, Metal Üretimi, Ok Ucu, Nif.

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1. Introduction

Pawlak's rough set theory is a mathematical method used in reasoning and information extraction for expert systems (Grzymala-Busse, 1988). As with fuzzy sets, the rough set theory does not accept strict limitations. After probability theory, fuzzy set theory and evidence theory, rough set theory is a new mathematical tool for dealing with vague, imprecise, inconsistent, and uncertain knowledge. In recent years, the research and applications on rough set theory have attracted more and more researchers' attention. And it is one of the hot issues in the artificial intelligence (AI) field (Pawlak, 2002). Making rules from data is extremely important in the interpretation process of archaeologists with such uncertain and vague information.

This paper proposes an application that extracts rough rules over data sets to understand the spatial context of a metal production area. The implication of the proposed method was processed through the data of 483 iron and bronze arrowheads dating back to the Archaic Period (6th Century BC), gathered from Karamattepe area at The Mount Nif Excavation, between 2006-2017. Since 2006 in Karamattepe stone foundations and some stone-wall remains of rectangular rooms, some with curved walls were unearthed along with circular pits, carved in bedrock (marl). This settlement belongs to the Geometric/Archaic Period due to the ceramics dated from the 8th century BC to the middle of the 6th century BC (Bilgin and Derin, 2013).

Wirth (1925: p. 175) said that "Each city, like every other object in nature, is, in a sense, unique". That quote can be considered as an inspiration for this study. The ambition in examining the Karamattepe data set based on the measurements of metal finds and geographical locations of both metal finds, and four metal production furnaces is its uniqueness as an unearthed Archaic Period metal production area in the Aegean district and, the uncertainty of the metric measurements due to corrosion, abrasion, and decay of the finds. Although various measurements have already been obtained from the 483 arrowheads, an original data set cannot be reached due to missing data during the excavation, impossibility to reach the findings a second time, and the corrosion of the gathered objects. Plus, the area, which has a natural incline in the north-south axis, had even been used as agricultural land for approximately 100 years in the modern period. As known, both natural slope and agricultural practices such as plowing and spudding in archaeological sites cause translocation, especially in small finds (Noble et. al, 2019; Lambrick, 2004; Talmage and Chesler, 1977). Under these circumstances, the context seems not suitable for spatial analysis with deterministic methods.

Aiming to understand the metal production system of Karamattepe a preliminary spatial analysis performed by grouping metal arrowheads with furnaces according to their geographical location and the measurements of the finds. It is accepted that the formerly mentioned nature of the site and the disturbance effect of agricultural practices such as plowing and spudding may cause dislocation especially in small finds increase the vagueness of the geospatial data of metal finds. By pursuing the stated objective, rough set-based spatial analysis method is proposed to illustrate relationships between small finds with production furnaces. Costin (2001) stated the factors identify a craft production system as Specialization (Production types and parameters, Components of production system, Identifying production system in the archaeological record), Producers (Specialists, artisan identity and social roles, Principals of recruitment), Means of production (Raw materials, technology), Organizing principles of the system (Spatial organization, Social organization, Standardization), and Objects (Function and meaning, Quantitative aspects of the demand). By this means, this study can be considered as an attempt to understand the spatial organization which is an attribute of the organizing principle of the whole metal production system. The outstanding aspect of the study is being an avant-garde in the context of archaeological spatial analysis by implementing rough set methodology to handle vagueness of spatial data.

In line with stated objective, the following sections of the paper include methodological information about rough sets and spatial analysis perspectives in archaeology, a literature review, a detailed introduction of the examined area, and the data at hand. In the last chapter, spatial analysis results of the proposed method are discussed considering the aim of the study, followed by suggestions for future methodologies.

2. Methodology

In this section, after explaining the preliminaries of the rough set theory, spatial analysis methods in archeology and their importance will be discussed.

2.1. Rough Set Theory

Rough set theory, introduced by Polish academic Zdzislaw Pawlak (1982) as a mathematical tool that overcomes uncertainties and vagueness. The rough set theory allows for validated logic, inconsistent data, and discovery of imprecise hidden inferences. Structures such as fuzzy and rough sets organize incomplete, insufficient, and uncertain information, making it suitable for data analysis. Also, rough set concept could be used in a more general setting, leading to advantageous applications in classification, clustering, taxonomy, etc. The main idea of rough set analysis is induction of approximations of concepts. In other words, if we consider every member of a set has some knowledge about the set by decreasing the crispiness of one set, we can increase our ability to find out patterns hidden in the set.

In rough set theory, data is stored in an indiscernibility table of characteristics and condition attributes. The theory has adopted the concept of equality class to divide learning data into sections according to certain criteria. In the learning process, two types of sections, lower and upper approximation, are created. From these concepts, which form the basis of the rough set theory, definite rules with the help of the lower approximation and possible rules, which may also be possible with the help of the upper approximation (Figure 1), are obtained (Pawlak, 1991, 1996 2004; Pagliani and Chakraborty, 2008).

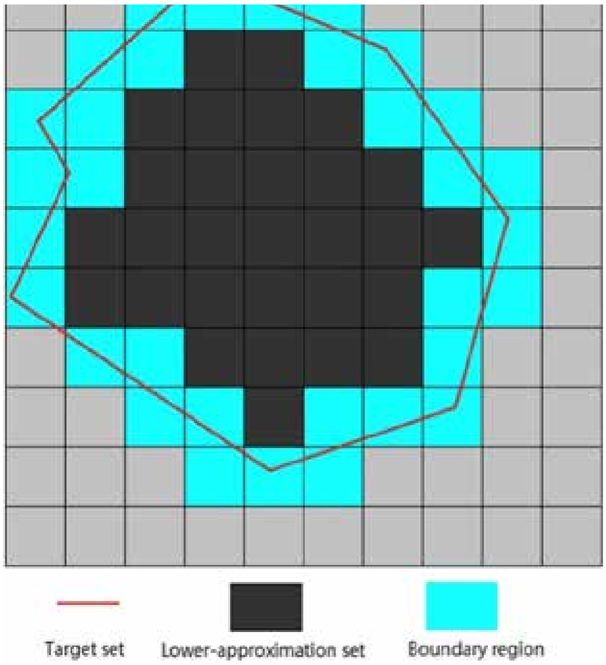

Figure 1. Lower and Upper Approximation Sets

2.2. Spatial Analysis in Archaeology

According to an early and basic definition of spatial analysis was done by Kintigh and Ammerman (1982), it is accepted as a process of searching for theoretically meaningful patterns in spatial data. The most common way of using the spatial analysis by archaeologists in visualization of the data on a map with relevant background information. Without doubt, the superior technology to accomplish this purpose is Geographical Information Systems (GIS) which was introduced in archaeology more than 30 years ago (Verhagen, 2018). GIS is a subset of the information systems which provide to collect, store, query, and display data with related spatial information. These technologies provide storage, monitoring and analysis by offline or real-time data collection from different sources such as networks, services, cameras, and sensors. As it is continuously streamed, the size of data can be huge and the growth in the unstructured data obtained from different sources introduced the term big data that is one of the most important trending topics in spatial analysis.

The spatial data is more important and valuable than ever before. The term "spatial" has emerged as an additional sense that can be understood as "space", which is monitored and sensed through electronic devices as a new cognition. Hahmann et al. (2011) states that most of the big data is georeferenced and 80% of it is spatial. Furthermore, as indicated by Lee and Kang (2015), the percentage of the geolocated data is drastically rising which is evidence that personal location data amount is increasing by 20% every year. To handle such geospatial big data collected from remote sensing methods (satellite images, GPS, Bluetooth, Wireless, etc.) have become crucial in many GIS applications. GIS can be defined as a computer-based data system. In this data system, it becomes possible to collect, analyze, and store all kinds of data located anywhere in the world. GIS helps to solve many social, economic, and environmental problems worldwide thanks to the large number of geographical information obtained by GIS is collected, analyzed and results are achieved (Chan et al, 2020). GIS is a concept that has a wide range of uses. This system, which can also be used as a database, provides data to institutions and organizations in many areas from infrastructure management to topological mapping (Lennox, 2012). According to Karataş and Kırbaş (2015), the GIS uses big data to help users in location-based decision-making processes and it solves complex social, environmental, and economic problems in the world. It is an augmented methodology, which brings software, hardware, method, geographic data, and personnel that fulfills the features of storage, collection, spatial analysis, processing, management, presentation, and query together.

In archaeological perspective, the importance of the use of GIS previously cited by Kvamme (1999), Verhagen (2007: 13–25), McCoy and Ladefoged (2009), Wagtendonk et al. (2009), Verhagen (2012), Hacıgüzeller (2012), Verhagen (2018) and Gillings et. al (2020). Spatial analysis is an important aspect of archaeological effort and has provided diverse insights into the behavior, social organization, and cognitive structures of past cultures (Robertson, 2006). Among the pioneers of the field; Hodder and Orton (1976), Clarke (1977), Flannery (1976), Hietala and Stevens (1977), Whallon (1973, 1974) Pinder et al. (1979) can be counted.

The examples of implementation of spatial analysis in archaeology via GIS technology are categorized as site location analysis, modeling movement and transport, and visibility analysis. As handled in this paper, site location analysis is one of the primary spatial analysis techniques which began to be used in analyzing site location preferences and prediction of the distribution of archaeological remains in the mid-1970s and 1980s (Verhagen, 2018).

3. Literature Review

According to Barceló (2005) an archaeological site can be considered as a place where a social action was performed. In the interpretation of this social action depending on the archeological evidence, the nature of the social movement, the effects of natural processes, and the post-effects of modern practices should be considered. In practice, all possible effects cannot be covered due to nature of uncertainty of handled information. By accepting the uncertainty as a part of the nature, fuzzy logic which is one of the widely accepted approaches in social sciences, found as useful in handling uncertainty (Lazar, 2002). Zadeh (1972, 1975), Yager (1986), and Atanassov (1986) made significant contributions to the field of fuzzy logic to reflect the human factor in decision-making processes. Another mathematical approach introduced by Pawlak (1982) is rough sets which offer a better alternative particularly in handling vagueness and uncertainty. As a digital archeologist, Barceló (2009: p. 105, 2010: p. 15) offered artificial intelligence (AI) based methods such as fuzzy logic, rough sets, genetic algorithms, neural networks, and Bayesian models in the field of archaeology. He found them robust and flexible compared to usual statistical methods in the presence of noise. In addition, these techniques can work with feature (attribute) spaces of very high dimensionality, they can be based on non-linear and non-monotonic assumptions, they require less training data, and make fewer prior assumptions about data distributions and model parameters. Furthermore, AI researchers have explored different ways to represent uncertainty: belief networks, default reasoning, Dempster-Shafer theory, i.e. (Russell and Norvig, 1995).

In the related literature, Banning's recent study (2020) provides a comprehensive overview of fuzzy applications with archaeological data, especially fuzzy clustering is extensively covered in the paper. Dallas (2016) cited importance of AI methods (i.e., fuzzy set and rough set theory, genetic algorithms) in archaeological knowledge gathering. Barceló (2016) cited recent research that applied previously mentioned

AI methods in the discovery of ancient settlements from satellite imaging, the study of geographical and cultural provenience of archaeological materials from spectrometry data and, unsupervised classification of archaeological images. In the literature review, related with the rough set applications in archaeological data discussed in this study, Lazar and Reynolds's (2003) study can be seen as a pioneer. That paper proposed a methodology to develop and model hypotheses and to derive patterns from archaeological data using heuristics. The methodology was based on rough sets as a knowledge representation for uncertainty in data, combined with the evolutionary algorithms. Another study belongs to Niccolucci and Herman (2015: p. 266). They proposed the usage of rough sets in managing the comparative dating of archaeological events as an extension of *terminus ante quem* and *terminus post quem* which are very common practices for assessing the chronological order of events.

As a result of the literature review, it was seen that the contribution and the robustness of the rough set theory, which is among the methods of AI, in the evaluation of archaeological data have been mentioned many times, but it is not one of the most frequently applied methods. In this context, it is hoped that this study will contribute to the literature in terms of including the application of the method through a different example.

4. Excavation Site: Karamattepe

Mount Nif, located east of İzmir, is within the borders of Buca, Bornova, Torbalı and Kemalpaşa districts (Figures a1-a2). Mount Nif with an elevation of 1,510 m is a mountain in the district of Kemalpaşa, towering over the district center, also formerly called "Nif", located immediately to the east of the city of Izmir. Excavations in Mount Nif, the eastern part of which is bordered by the Karabel Rock Monument, are on the southeast cliffs. Excavation areas are named as Karamattepe, Ballıcaoluk, Başpınar and Dağkızılca. Since 2008, these areas were registered as "First Degree Archaeological Sites" by the claim of Second Regional Commission for Conservation of Cultural and Natural Properties of Izmir. Excavations were directed between 2006-2019 by Prof. Dr. Elif Tül Tulunay (Istanbul University) and they are carried on since 2020 by Doç. Dr. Müjde Peker (Istanbul University) (Tulunay et al., 2019).

Karamattepe is considered as a metal production area in the Archaic Period, which outshines with rich metal finds such as nearly 500 pieces of iron and bronze arrowheads (Figure a4), and iron ingots (Figure a6). Plus, there are many terracotta tuyeres (Figure a5), four metal production furnaces (Figure a3), pits (*bothroi*) (Figure a2), and many slags which are the indications of the forging stage (Figure a6) were found in excavations. Besides, the environment of the excavation area is naturally surrounded by large woodlands and water resources. Under the light of these factors, it can be concluded that the region is suitable for metal production. However, although many arrowheads and slags were gathered during the excavations, no molds were found. Considering the value of the molds used in the production process, it is accepted as a priori information that the manufacturers took the molds when they left the area. Considering twelve inhumations and two cremation graves excavated in 2006-2010, it is probable that this area was used as a necropolis in the Hellenistic Period. The site has a natural incline in north-south axis, furthermore, it had been used as agricultural land for approximately 100 years in the modern period (Baykan, 2015a; 2015b).

When the bedrock floor traces were examined in Karamattepe, some evidence regarding the possibility of silver separation and cupellation were observed here. In addition, a multi-pit ore enrichment stone was found. A detailed of mentioned ore enrichment stone was published by Kaptan (2015). Karamattepe Furnace I is a furnace with a pitless base detected in 2011. It has an inner diameter of 37 cm, a preserved height of 20 cm, and a wall thickness of 3.5-5 cm. Furnace II is also a furnace with a pitless base detected in 2012. It has an inner diameter of 41/44 cm, an outer diameter of 53/56 cm, and a wall thickness of 4-7 cm. The exterior was supported by large pieces of terracotta vessels. Furnace IV was found in 2014 and is a furnace without a pit. It has a form and close dimensions just like Furnace I and II. It is in trench AA33d. By looking at the slope on the inner walls of Furnaces I, II, and IV, one can imagine a smelting furnace with at least one bellow opening close to floor level. These three furnaces have a floor-mounted top opening, built in a cylindrical form with mudbrick, with an opening for the bellows at floor level and possibly smaller than the base width. This type of furnaces are used as smelting furnaces in iron metallurgy under the knowledge of ethnoarchaeological sample comparisons and the visual information that has survived from the ancient examples. Furnace III was excavated between 2014-2015. It is at the border of AA33a and AA35b trenches and it is quite different from the furnaces discovered in previous years. Furnace III is larger than the other three, unlike the others in terms of material. It is partly built with rubble stone and mud-plastered, and above all, it is supported in the center. Its support with a height of approximately 40 cm constitutes 54 to 64 cm of the approximately 1-meter inner opening of the furnace. The diameter of the furnace, which has a very irregular circular form, varies between 1.33 and 1.60 m. It certainly differs from the other three furnaces due to its form and material. Moreover, although the other three furnaces are built entirely of mud, it does not keep the color and texture with the mud used in the plaster of Furnace III. For these reasons, Furnace III, where cream-colored plaster was seen, unlike the other three kilns built of red clay, was probably built in the first metalwork phase of Karamattepe. It might belong to the 7-6th century BC (Baykan, 2017).

In Karamattepe, with preliminary determinations made by archaeological observation, typology, classification, and analogy methods, possible silver/gold with melting, bronze and lead casting, iron smelting and forging processes was determined. With the interpretation of the contexts, it was determined that there are two different workshop phases, and they belong to different consecutive times. The first metalworking phase (7-6th century BC) includes bronze, copper, and silver/gold? casting. That phase must contain Furnace III. The second metalwork phase (after 546 BC) includes iron smelting/forging, perhaps lead casting and Furnace I, II, and IV for Persian army ammunition (Baykan, 2017).

5. Dataset

Within the excavations between 2006-2017, a total of 483 arrowheads made of iron and bronze have been unearthed. A typological study was carried out by Baykan (2015a) and arrowheads were classified into seven different categories. In 2017, first digitalization was made for all metric and spatial data of arrowheads. Table 1 shows the distribution of a total of 483 arrowheads, 468 made of iron and 15 made of bronze.

Table 1. Frequency Distribution of Arrowheads According to Typological Classification

Type	1	2	3	4	5	6	7	N/A
Frequency	289	129	28	13	8	5	2	9

Though many variants within 10 years of collected data and various losses due to missing measurements have been discovered. On the other hand, Table 2 shows the missing data frequencies for the arrowhead dataset variables in detail (Tuncalı Yaman, 2019; 2020).

With the help of an imputation study performed by Tuncalı Yaman (2020), missing data were imputed by a fuzzy approach to Markov-Chain Monte Carlo (MCMC)-based Multiple Imputation (MI) technique. In this study, the previously imputed data set was used. Nevertheless, it would not be reliable to impute missing geospatial data and existence of absence as a categorical feature. Thus, analyses based on rough sets were performed only with 420 arrowheads which have the geospatial location data. Also, all covered arrowhead data include information of absence attribute. Selected attributes for rough set-based spatial analysis are; Material (Bronze/Iron), Type (1-7) Absence (Y/N), Weight, Length, and Elevation. Geographical Euclidean proximity to furnaces (I-IV) is defined as decision criteria.

As a separability index, the Euclidean distance is used mainly in classifications where the minimum distance algorithm is applied. This method simply calculates the Euclidean distance between a pair of observations (Agapiou et. al, 2012). The equation of the metric is presented below (You et. al, 2019:72).

$$d = \sqrt{(x_i - x_j)+(y_i - y_j)} \forall i \in A, j \in F$$

Where:

d: Euclidean distance
x_i: x-coordinate of the arrowhead i
y_i: y-coordinate of the arrowhead i
x_j: x-coordinate of the furnace j
y_j: y-coordinate of the furnace j
A: Set of arrowheads, $A = \{1, \dots, i\}$
i: Index of arrowheads, $i \in A$
F: Set of furnaces, $F = \{1, \dots, j\}$
j: Index of furnaces, $j \in F$

Table 2. Missing Data Frequency Distribution of Arrowheads According to Measured Attributes

Variables	Observed Data	Missing Data	
		Frequency	%
Weight (g)	456	27	6
Length (cm)	471	12	2
Width (cm)	324	159	33
Thickness (cm)	220	263	54
Case Width (cm)	110	373	77
Helve Thickness (cm)	295	188	39
Stem Width (cm)	28	455	94
Driller Length (cm)	425	58	12
Elevation (cm)	419	64	13
Absence			
Yes	103	42	9
No	338		
Material			
Iron	468	-	-
Bronze	15		
Geospatial location	420	63	13

The decision criteria attribute of arrowheads was coded as 1 to 4, according to the minimum distance measured among four furnaces. For instance, the geospatial location of an example type 3 arrowhead (Inventory #: M.10-1) is (533476.04,4244231.50). Calculated Euclidean distances as to four furnaces are 26.90, 26.06, 55.81, 59.35 respectively. Decision criteria of this arrowhead coded as 2 (indicating Furnace II) by selecting the minimum Euclidean distance value.

6. Results

To perform rough set-based rule generation process, Rose (Rough Set Data Explorer) System (Web1, 2021), which is a toolkit for pattern recognition and data mining within the framework of rough set theory, was used (Predki et. al, 1998; Predki and Wilk, 1999). The related R-Packages of the technique are *RoughSets* and *RoughSetData*.

Table 3. Sample Information Table

Inventory #	Material	Type	Absence	Weight	Length	Elevation	Decision Criteria
M.10-1	Iron	3	No	8.6	8	438.18	2
M.10-23	Iron	1	No	5.4	3.8	437.37	2
M.10-3	Bronze	5	No	3	3.8	438.37	2
M.16-2	Iron	1	Yes	9.05	8.5	436.37	4

Before preprocessing the data, a sample information is given in Table 3. Data exploration process using ROSE system represented in Figure 2 (Predki et. al, 1998). Prior to analysis, data preprocessing is made by gathering discretization table of the data. Since, the data have no missing values, rough approximations were made based on previously calculated discretization matrix. By performing heuristic search in the ROSE all attributes except Material, are selected in core attributes in rule induction. In total, 214 rule inducted by the information system.

The most significant approximation rules are given below.

rule 181. (ABSENCE = No) & (WEIGHT = 7) & (LENGTH = 5) & (ELEVATION = 438) => (Furnace = IV) OR (Furnace = I) OR (Furnace = II); 62.50%
rule 182. (ABSENCE = No) & (WEIGHT = 14) & (LENGTH = 6) & (ELEVATION = 438) => (Furnace = IV) OR (Furnace = I) OR (Furnace = II); 37.50%
rule 183. (WEIGHT = 7) & (LENGTH = 6) & (ELEVATION = 438) => (Furnace = IV) OR (Furnace = I); 54.55%
rule 184. (WEIGHT = 7) & (LENGTH = 5) & (ELEVATION = 439) => (Furnace = IV) OR (Furnace = I); 45.45%
rule 185. (TYPE = 1) & (WEIGHT = 8) & (LENGTH = 5) & (ELEVATION = 438) => (Furnace = IV) OR (Furnace = II); 42.86%
rule 187. (TYPE = 1) & (WEIGHT = 10) & (ELEVATION = 437) => (FURNACE = 3); 28.57%

Interpretation of the rules could be done according to the specs that are given into parentheses, like reading the steps of an algorithm with AND and OR keywords. For instance, Rule 181 indicates that such finds with no missing parts AND Weight equal to 7g AND Length equal to 5 cm AND Elevation equals to 438 cm would be in a relation with Furnace I OR Furnace II OR Furnace IV with a 62,5% likelihood level.

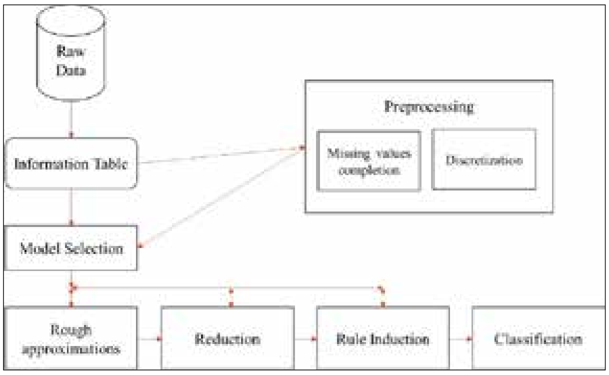

Figure 2. Scheme of Data Exploration in ROSE

For different furnaces, to determine lower/upper approximations of the set and the boundary sets, every granule is controlled. This control is done to find out whether a furnace is a subset of their respective sets. The lower approximation set to set Furnace I of rough set is the combination of granules that are subsets. The lower approximation set has 136 elements. The upper approximation set is the intersection of the set Furnace I and the non-empty sets. The upper approximation set has 219 elements (Table 4). For Furnace I, the lower and upper approximation sets are not the same. The boundary set of Furnace I is calculated as follows:

$$Bnd(Furnace\ I) = \overline{Apr}(Furnace\ I) - \underline{Apr}(Furnace\ I)$$

When $\underline{Apr}(Furnace\ I) \neq \emptyset$ and $\overline{Apr}(Furnace\ I) \neq U$,

the Furnace I set can be roughly defined in relation to the rough Furnace I. Since the lower and upper approximations are not the same, it can be claimed that $\overline{Apr}(Furnace\ I) \neq \underline{Apr}(Furnace\ I)$ a boundary set exists. The boundary set is a set consisting of 83 elements. The consistency factor (γ) is the ratio of the cardinality of the lower approximation to the cardinality of the upper approximation. The consistency factor of Furnace I is calculated as follows:

$$\gamma(Furnace\ I) = \frac{|\underline{Apr}(Furnace\ I)|}{|\overline{Apr}(Furnace\ I)|} = \frac{136}{219} = 0.6210$$

Table 4 shows the lower and upper approximations and boundary sets of furnaces, and the consistency factor figures as approximation accuracy of the calculations.

Table 4. Lower and Upper Approximations and Boundary Sets

Furnace	# of objects	Lower approximation	Upper approximation	Boundary set	Consistency factor
I	178	136	219	83	0.6210
II	182	136	229	93	0.5939
III	43	34	62	28	0.5484
IV	16	7	33	26	0.2121
	420				0.7470

According to Table 4, many of the examined arrowheads have high relation with Furnace I and II. The lower approximation, that is, the number of granules in the set is higher for Furnace I and II. The upper approximation shows the granules whose intersection with the set is not empty. In the upper approximation, granules belonging to Furnace II are higher.

Relation of arrowheads with Furnace I has the highest approximation accuracy whereas there are more elements classified with Furnace II. The total number of arrowheads related to Furnace III and IV which are located on the uphill southern side, relatively low according to I and II. This result is consistent with the natural specs of the site and archaeological interpretations in terms of chronological and formal features of the furnaces.

According to the archaeological and archeometallurgical interpretations through the data set that is the subject of this study, Karamattepe has two separate metalworking phases. The first phase (625-546 BC) was related to bronze casting, copper, and possible galena silver/gold metallurgy and the second phase (546-510 BC) was involved in ferrous metallurgy/forging, lead casting (Baykan, 2017; 2021). In agreement with the distribution of the rule set associated with the furnaces, it is observed that more finds were obtained from the second metalworking phase than the first. Furnace III, which differs from the others structurally, is dated to the first phase, and Furnace I, II, and IV are belong to the second phase. In line with the stated interpretations, Furnace III is not included with others in the rules with high likelihood. This shows that the ruleset gives compatible results with the chronological and production purpose difference pointed out by Baykan (2015a, 2015b, 2017, 2021). On the other hand, one of the important features of the excavation area is that it has been used in agricultural activities for a long time and that the layers that can be used to determine different phases are highly likely to be degraded due to its natural slope. Similarly, the "Elevation" variable does not take significantly different values in the rule sets associated with furnaces dated to two separate phases (Furnace III vs Furnace I, II and IV). Thus, it can be said that the proposed rough set-based approach seems able to put forward an argument that helps decision-making, while it considers the uncertainty created by this variable in the inference phase.

7. Conclusion

In this study which aims to understand a metal production area in Karamattepe which is a well-examined sample from Western Anatolia in Archaic Period via a spatial analysis which covers specific attributes of products (as arrowheads) with spatial distribution and geolocation of four furnaces as a core production element, a rough set-based approach was pursued. Since the nature of the metal finds as elements of rough set information system and spatial characteristics of the site such as natural incline in the north-south axis and being an agricultural land in the modern period led us to follow a rough set-based methodology which is considered as a useful tool in handling uncertainty of the data.

In this context, metric and geographical data belonging to 419 arrowheads were associated with 4 furnaces in the area according to their Euclidean distances. Spatial distances of arrowheads to furnaces were used as inputs in the information system and were defined as the decision criteria. Gathered classification results of rough set-based spatial analysis are found explanatory in sense of prior archaeological interpretations.

Even though AI-related techniques such as fuzzy logic and rough sets were recommended by researchers in the last decade, practical applications are very limited in archaeology. There are promising examples of the utilization of fuzzy approaches. For instance, Qiang et al (2009), in their conference proceeding, implemented the rough-set theory in the analysis of imprecise temporal information. Hermon and Niccolucci (2017) were proposed the use of rough-set-based fuzzy approaches in defining the relation of time, space, and culture. In her paper, Figuera (2018) presented the use of fuzzy sets in the management of an archaeological database. An analysis with fuzzy sets methods in the spatial clustering of pottery finds was realized by Tirpáková et al (2021). The fact that the archaeological research problem posed in this study has not been handled with a similar approach before and that the results obtained are supportive of archaeological and archeometallurgical evaluations reveal the value of the study.

The limitation of the research is the lack of geolocation data and dating information (Archaic or Hellenistic?) of slags and other production-related materials (such as terracotta tuyeres, iron ingots, etc.). This is the reason why the studied data covers only arrowheads. For future research, archeometallurgical analysis results of various metal finds will be included in the analysis as additional attributes.

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Appendix

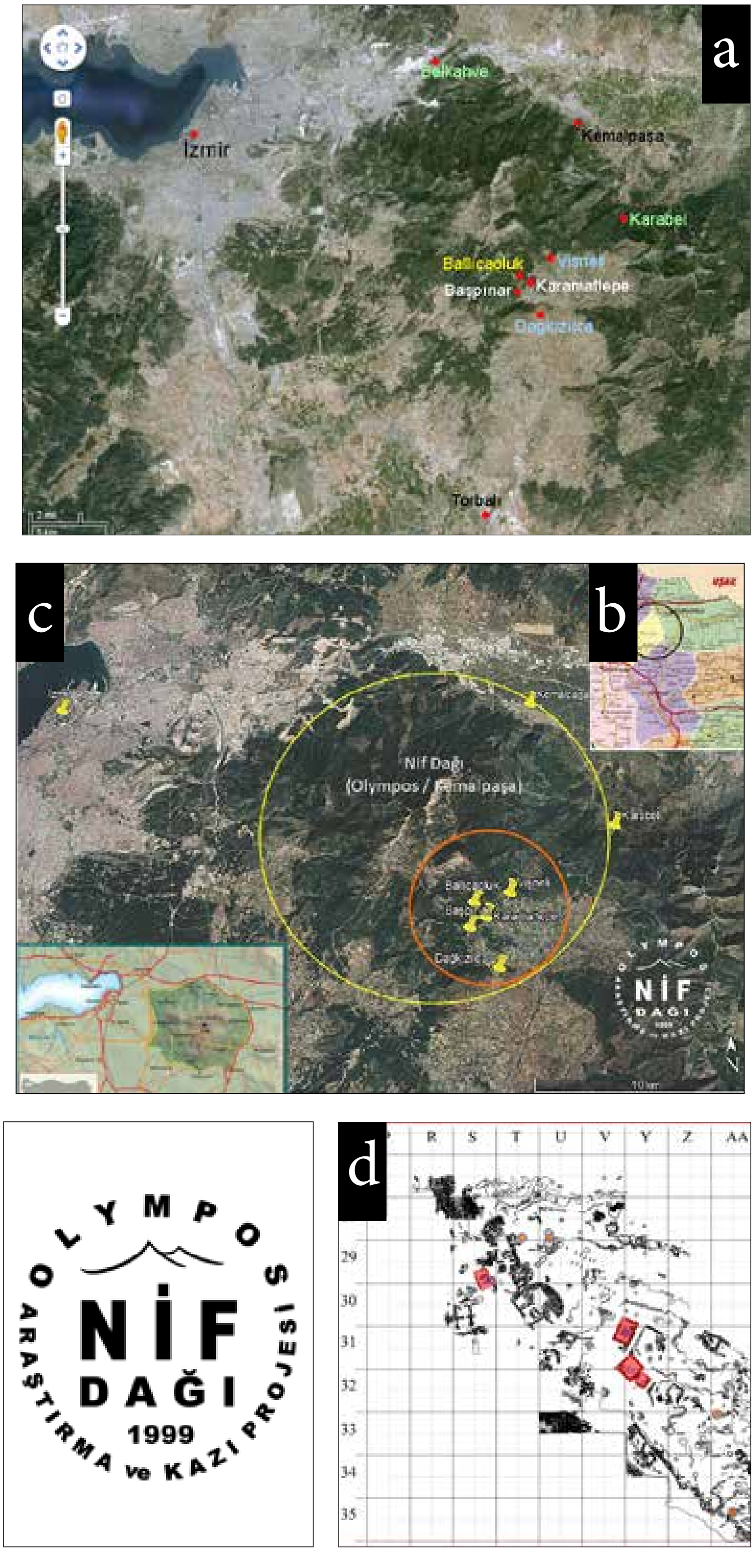

Figure 1: Mount Nif - a, b, c) Map and Satelite View; d) Karamattepe 2018 plan. (Tulunay et. al, 2019).

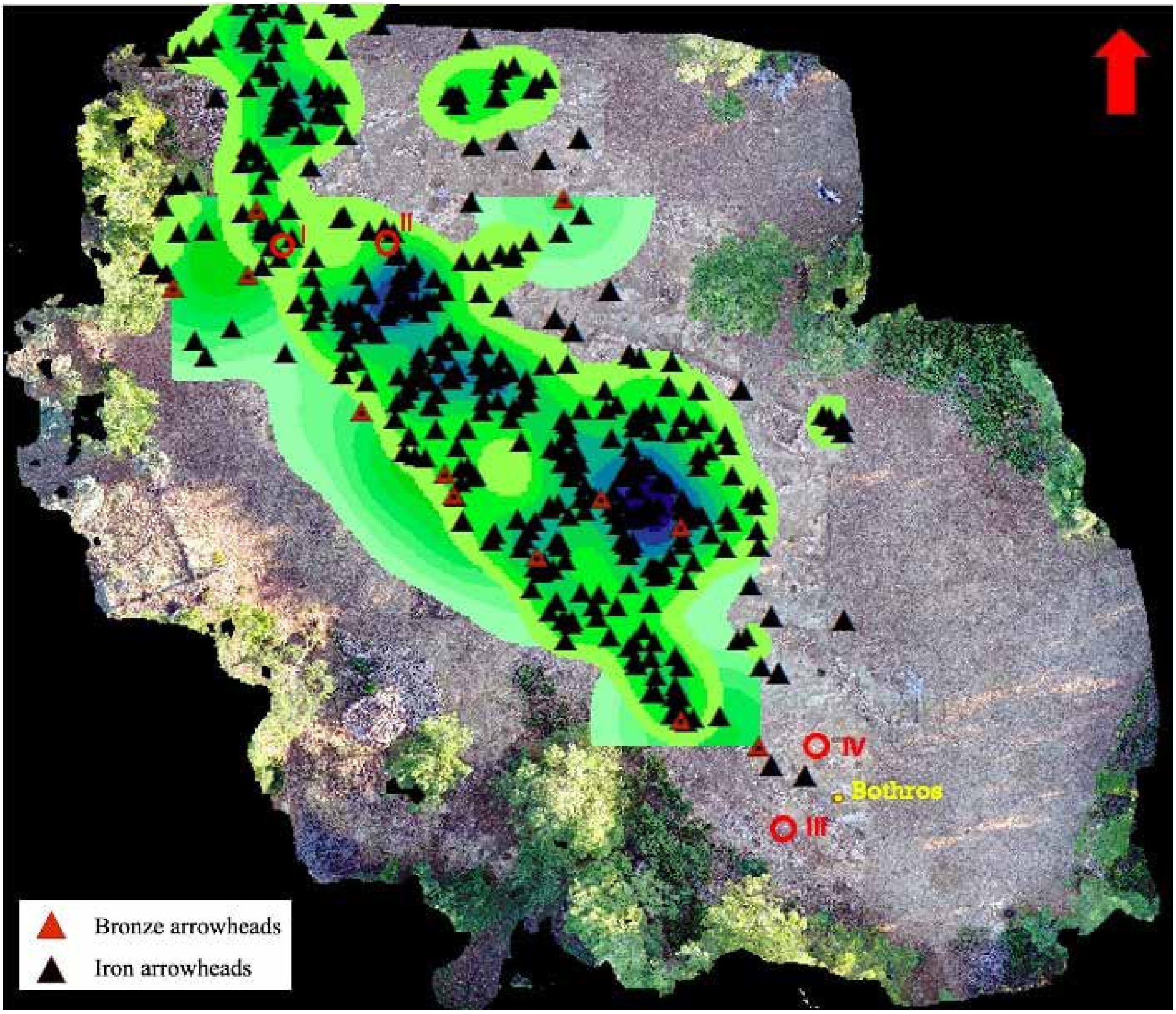

Figure 2: Orthophotography of Karamattepe with Geolocations of Arrowheads with Intensity Map and Denoted Locations of Furnaces (I-IV) (Photo: The Mount Nif Excavation Archive)

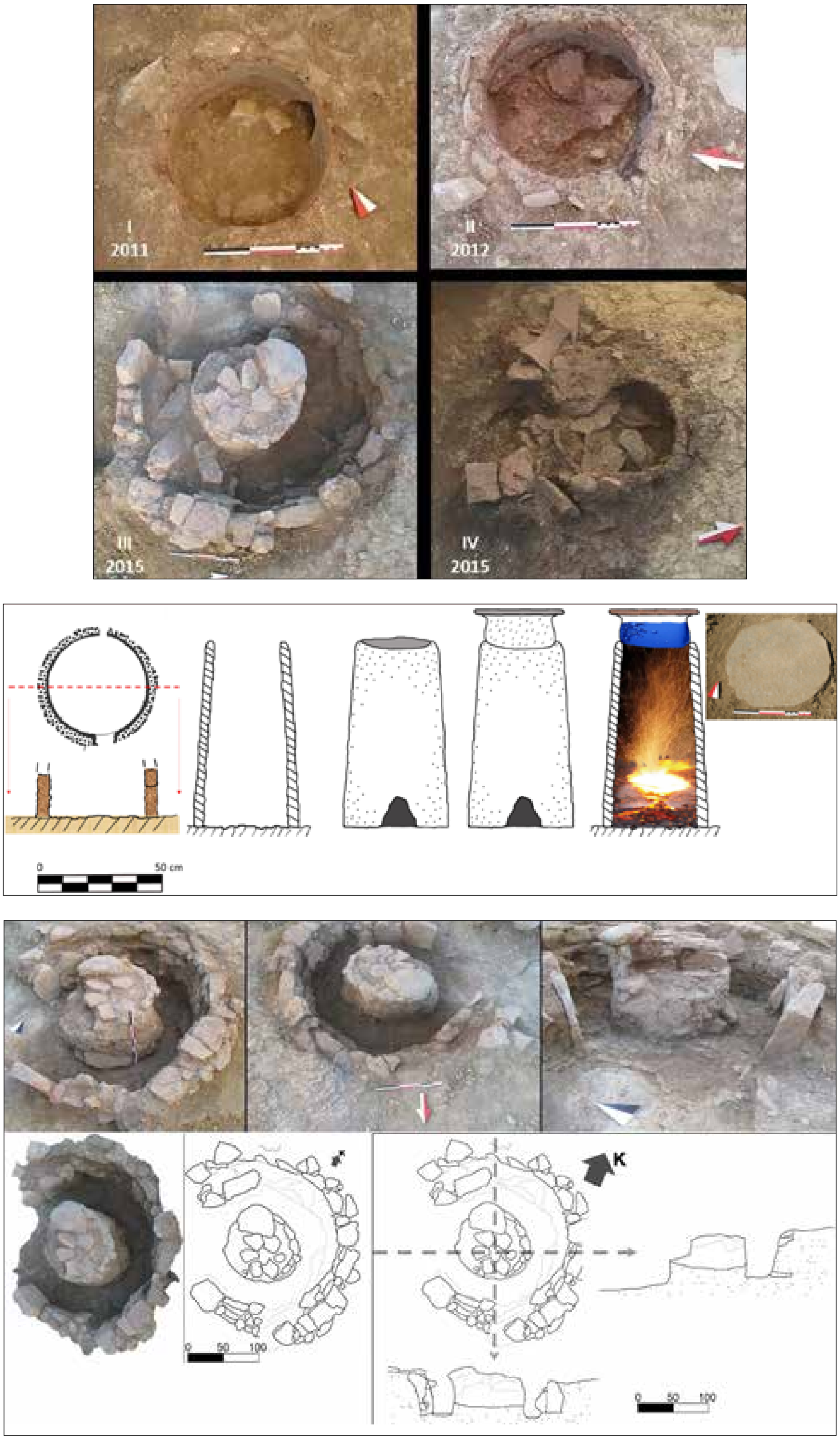

Figure 3: Furnaces (Photos and Illustrations: Ceren Baykan)

Figure 4: Arrowheads with Typology (Photos: Ceren Baykan) (Baykan, 2015a)

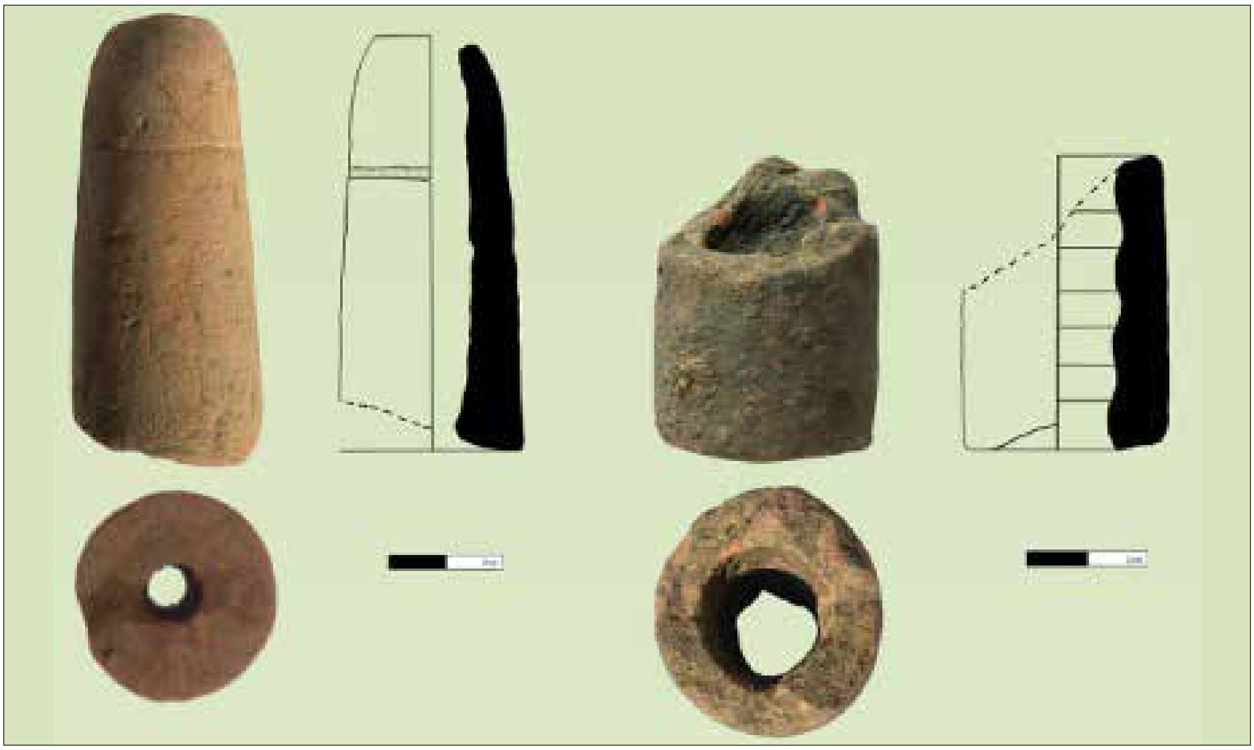

Figure 5: Terracotta Tuyeres (Photos and Illustrations: Ceren Baykan)

Figure 6: Slags, Iron Ingots, Tuyeres and Forging Stage Finds (Photos and Illustrations: Ceren Baykan)