Title!

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abstract

1 introduction

This paper explores the question: how much can the chemical composition of pottery fragments tell us about the evolving connections between settlements in Bronze Age Greece?

2 literature review

In this section, two categories of literature are surveyed: (a) theories of Bronze Age trade relevant to the movement of ceramics, and (b) relevant archeometric and modeling methods.

Our dataset includes ceramic shreds from the 7th century BC to the Roman period, but mainly consists of works from the Late Helladic Period - III (LH III, see fig. 1 for a chronology) fig. 2 is a map with dashed lines encoded hypotheses about prominent sea routes in the late Bronze Age.

Maps like fig. 2 are of tremendous historical significance if they can be constructed accurately. A common way to map trade is to identify artifacts that have been transported from their location of origin. How do researchers infer where ceramic objects and shreds originate?

3 Motivation/Dataset

3.1 Motivation and Summary Stats

Archaeological studies has been actively inviting the analytical methods from the entire spectrum of social science studies. However, when it comes to the application of machine-learning techniques, we have not seen much done recently. Therefore, we set out to explore the archaeological databases, searching for datasets that are rich enough, in terms of dimensions of the observables.

Baring the capability of machine-learning in mind, we found the Lawrence Berkeley National Laboratory (LBNL) Nuclear Archaeology Program Archives of particular interest, as it not only contains geographical and historical records of the artifacts, it also carry the chemical compositions for most of its records.

Due to limited time and resources, we focused exclusively on the Greece records, totaling 886 pieces of artifacts from ancient Greece, discovered from 31 archaeological sites[1]. The time frame in our sample covers from the Early Helladic era (around 3200 BC) to Roman Republic.

3.2 Data manipulation

For the records of artifacts from Greece, the dataset came with 1,198 observations in the begining, pulled directly from `http://core.tdar.org/`[2] The variables include the discovery site, the

[1]30 in Greece, and one (Perati in Attica) in Turkey.

[2]To take a quick look at the artifacts, please refer to 3.

associating era, geo-coordinates and the chemical compositions of 33 elements[3]. However, the chemical composition data is not complete. Thus, we dropped a subset of observations as well as insignificant variables of elements (Sb Ba As Sr V) to obtain a sample of 886 observations.

4 Problem Formulation

5 problem formulation

Our goal in this project is to understand relations of evolving similarity between archeological sites over time. In this section, we define this problem more exactly.

First, a brief intuitive gloss on our technique. In our model, similarity reflects a relationship between our estimates of the underlying functions which are 'generating' the artifacts. By modeling it this way, we reduce the site information to an underlying probability function. Then, these functions can be compared, and a relationship computed pairwise between all the sites. This allows us to construct a network. Finally, we can look at the network among sites over the entire period, or segmented by time. In the latter analysis, we separate the artifacts into eras, and look at the similarities in each era separately.

What is this analysis meant to accomplish? Archaeologists have looked at Greek pottery artifacts for centuries in an attempt to understand trade, and each individual site we consider has been described in elaborate detail (for example, see [**davis1979late**]). Our project is meant to be *focused and precise* in its use of data, while aiming at a *general and holistic target* - simplicity of element abundance profile. This might seem like an odd mismatch, but it also has the potential to either turn up novel connections or confirm old results from a fairly independent source.

So the problem we are attempting to solve is to take a well-defined but limited set of features (element abundance) and generate a similarity network using only those features. Then, we will compare the relations in our network to theories and findings from archaeologists and historians about the trade and migration patterns that might effect the similarity of pottery artifacts. In the most general case, we consider the progression of trade power (among our sites, a progression from Aegina in the early Bronze Age, to Festos in the Minoan period, then Mycenae in the late Helladic, and finally Berbati). These theories of trade relations also imply similarity relations - just of a more qualitative kind, and based a far wider body of evidence. Finding significant points of agreement between our model and these theories would be an indication that the similarity relation we've calculated based on these simple chemical properties is latching on to something deeper. This could be because of similarities in raw materials, or firing techniques, but most likely a combination of the two. Alternately, finding unexpected similarity relations or relations that run contrary to extant archeological theories might be a call for explanation: could there be a genuine trade connection between these regions? Or if not, could the similarity in composition of the shards be reflection some other kind of connection?

In short, we view the application of machine learning techniques to archeology as aiding in a discovery process. The discovery process in question in this paper is comparing quantitative similarity of chemical composition of pottery to qualitative similarity of regions based on extant theories of influence, migration and trade.

7000	Beginning of widespread use of pottery in Mediterranean. Aegina as maritime center
3200-2000	Early Helladic
3200-2500	High point of Anatolian trade network
2000-2200	Disruption of trade between Cyclades, Mainland, and Crete. Upheaval in Mainland
2000-1550	Middle Helladic. Protopalatial and Neopalatial buildings in Crete
1650-1500	Late Helladic I / Late Cycladic I / Late Minoan IA
1500-1400	Late Helladic II
1400-1300	Late Helladic III A
1300-1200	Late Helladic III B. High point of Mycenaean influence on trade
1200-1050	Late Helladic III C
1050-	End of Bronze Age. Transitional Period: Argos, Asine and Berbati rise to prominence.

Figure 1: Timeline of Events of Interest (all dates B.C.)

6 Methdology

7 Results/explanations

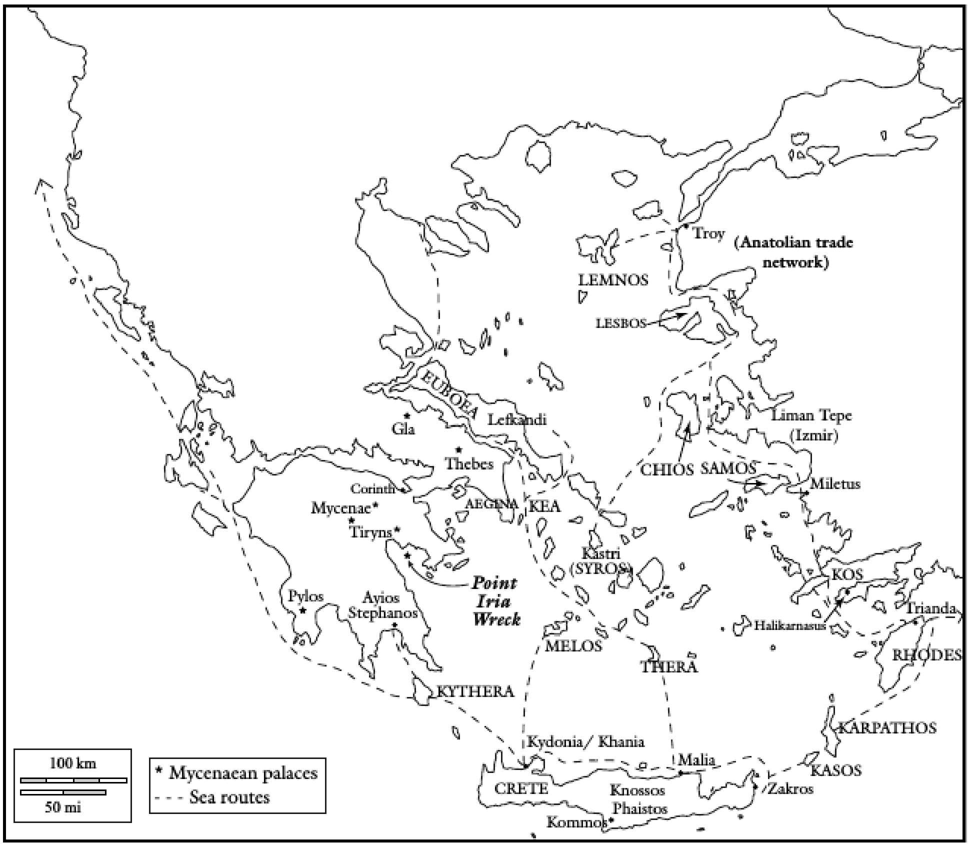
8 Conclusion

Qualitative methods include categorization by geometric features, and material features. For instance, Davis[**davis1979late**] classifies pieces from LH I Korakou by shapes, as well as surface and burnishing, measured by the eye against a color chart. The task is to sort shreds and pieces by style, and also material - these two elements are necessary to differentiate cases where a style travels but pieces are built from local materials. A qualitative study we'll discuss in detail later is that of Rutter[**rutter1975ceramic**] - he uses the shapes and visible properties of pottery found in Korakou to argue that those pieces were erroneously categorized as Mycenaean. That is: qualitative differences are used to prove a classification claim.

Quantitative work in classifying pottery mainly uses data from neutron activation analysis or spectral analysis of paints. This paper uses a neutron activation analysis dataset from the LBNL archeometry archives. The extant work on this dataset (which contains subsections for many geographical areas across the world) has mostly been conducted by Mommsen and colleagues. This work has two main goals: first, to be a proof of concept for quantitative analysis by reproducing known results from limited data, and second, to discover previously unknown connections as a bridge for further inquiry, both qualitative and quantitative. So for instance, in [**mommsen2002complete**], Mommsen et al take their model to succeed by matching existing predictions about early recipe variation in Argolid pottery suggested by Hoffman et al, and by adding new predictions in the case of suggesting a pattern of export from Chania to Cyprus of cream ware. Grave et al[**grave2014ceramics**] follow a similar method of combining the LBNL dataset with other information, also with Cyprus late Helladic wares.

9 method

[3]Elements are: *Al Ca V Dy Mn Na K Sr As U Eu Ba Sm La Ti Lu Nd Co Sc Fe Ce Yb Cs Ta Sb Cr Th Ni Rb Tb Hf Zn*



Map 7.3 Mycenaean palaces and Aegean maritime routes.

Figure 2: image from [**demand2011mediterranean**]

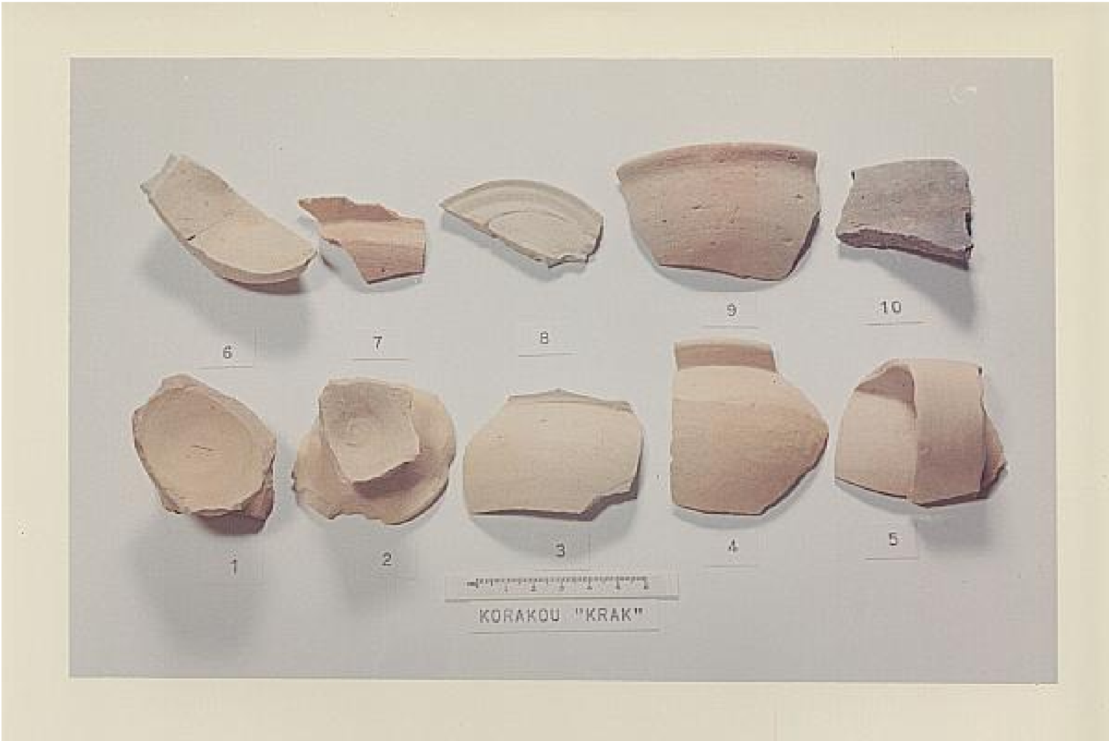


Figure 3: Example of shreds in the database