Chapter 14

Interregional Interaction and Dilmun Power in the Bronze Age: A Provenance Study of Ceramics from Bronze Age Sites in Kuwait and Bahrain Using Non-Destructive pXRF Analysis

Hasan J. Ashkanani[*] and Robert H. Tykot

Department of Anthropology, University of South Florida, Tampa, Florida 33620
[*]E-mail: hasan@mail.usf.edu

Known as the most interactive period of trade and interregional interaction, Dilmun led and controlled the flow of commodities and the transshipment between Arabian Gulf political entities such as Mesopotamia and far distance ones such as the Indus Valley. This paper presents the first provenance study on 2nd millennium Dilmun pottery in the Arabian Gulf, specifically Kuwait and Bahrain. Our aims are to construct a chemical database of Bronze Age ceramics and to discuss standardization of Dilmun wares using trace elements Nb, Th, Sr, Y, Zr, Rb, and Ba obtained with a non-destructive portable X-ray fluorescence spectrometer. Multiple spots on artifact surfaces were tested to inspect the quantitative precision of the technique and the homogeneity of ceramics was analyzed non-destructively.

Introduction

Dilmun Culture

Dilmun is the name of a political and cultural entity identified by the Sumerians. The Dilmun culture spread from Bahrain circa 2500 BC and some evidence suggests its earliest development began on Tarut Island in the early third millennium (*1*). In general, Dilmun refers to a culture that thrived in modern-day Bahrain, the Eastern Province of Arabia, particularly Tarut Island, Saudi Arabia, and Failaka Island, Kuwait. The Sumerians relied on Dilmun agents to transship

or move raw materials and products back and forth along local waterways and sea routes from southern Mesopotamian ports to their trading partners as far away as Magan in southeastern Arabia and the Indus Valley (see Figure 1). The lack of raw materials in Mesopotamia propelled southern cities to trade with neighbors to acquire metals, wood, onions, shells, ivory, and pearls in exchange for textiles and wool (*2*). Thus, establishing and maintaining trading routes was a major catalyst for the development of Dilmun culture in the Arabian Gulf coastline during the third and second millennia BC. Centrally located in the Arabian Gulf, Dilmun acted as an entrepôt in this long-distance trade linking two large civilizations - Mesopotamia and Harappa.

Dilmun sites are characterized by the presence of 'Dilmun' type seals, chain-ridge pots, red-ridged Barbar ware, and burial mounds. In Bahrain, the Dilmun culture consisted of two major horizons, the Period I or pre-Barbar period (2150-2050 BC) and the Barbar period (2050-1800 BC). Period I is known for the chain-ridged pottery type and a settlement at Qala'at (*3*). Also, the chain-ridge ware type has been identified as Period I or pre-Barbar period in Bahrain, below the early second millennium temple of Saar and from the Eastern Province, on Tarut (*1*). The Period II or Barbar culture has been characterized by the presence of the temple complex, Dilmun/Gulf seals, burial mounds, red-ridged Barbar ware, and settlements at Saar, Diraz, Hamad and Hajar. The Barbar Period, also called the Early Dilmun period, is associated with dramatic expansion within the Dilmun territory and northwards. The presence of the Dilmun culture has been established on Failaka Island, Kuwait from the excavation of different sites, dated to ca. 2000 BC (*1*, *4*).
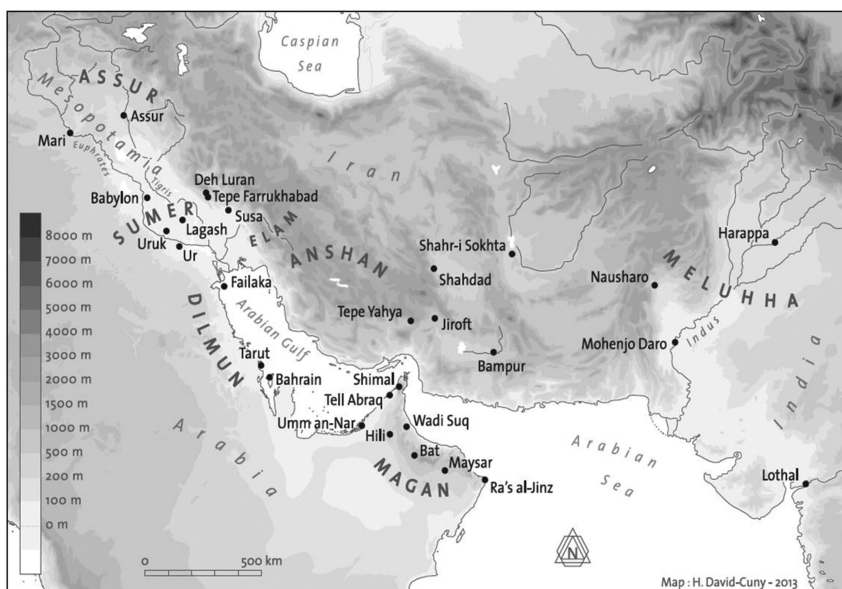

Figure 1. Map of the Arabian Gulf and adjacent regions showing the major sites and locations mentioned in this text. (Drawing by Hélèn David-Cuny).

Dilmun's Emergence in the Trade Network

Dilmun was favored as the most active entity in the Persian-Arabian Gulf in the early second millennium and transshipped commodities to different regions and dramatically expanded its territory and prosperity (*2*, *5*). Unlike during the 3rd millennium BC, Dilmun would dominate the Mesopotamian trade network in the 2nd millennium BC by expanding to the north, including Failaka Island in Kuwait (Figure 1). During this period, its centers and ports became attractive to traders looking for markets where there was a reliable supply of raw materials and the flow of commodities was secure (*6*). Even though Dilmun's influence in the Gulf region was not prominent until the second millennium BC, it still played a vital role in third millennium trade and exchange. It was a middleman for the copper trade between Mesopotamia and Magan (Oman). Textual evidence from the Early Dynastic mentioned cargos of woods, merchants, and boats shipping from Dilmun (*6*). A textual account from King Sargon (ca. 2334 BC) is one of the most cited references by archaeologists and historians describing the nature of ancient trade in the region. The latter record contained references to the involvement of Dilmun in third millennium trade and its role as one of the smaller entities under the expansion of Akkadian power. Also, it referred to the other neighbors, besides Dilmun, who participated in the extensive trading connection with Mesopotamia as he was proud to receive ships from Meluhha, Magan (Oman), and Tilmun (Dilmun) and moored in front of Akkad (*6*, *7*). This record implied that Akkadian control over the Gulf was extensive, leaving little room for smaller polities to have influence - a loss of 'middlemen' such as the Elamites, the Iranians, and the Dilmun during this period. Several texts from the late third millennium BC, Ur III period, further indicate Dilmun/Magan trade as organized by the temple.

Failaka Island Significance and Research Question

After the collapse of Akkad, Dilmun came to dominate the Arabian Gulf through the control of transshipping different commodities. Ur III and Isin-Larsa tablets and texts (period 2112-1763 BC) testify to the role of Dilmun in the trading activity of merchants and objects going from Dilmun to Ur (*6*, *8*, *9*). It seems Failaka Island was part of Dilmun's administrative strategy to expand its borders and secure a refueling station to its seafarers and the merchants (Figure 2). In the beginning of the second millennium BC, Failaka Island was a Dilmun port and the nearset point on the Arabian Gulf to Mesopotamian. The different trading products to and from Ur, Harappa in the Indus Valley and Oman such as wood, shells, pearl, onions, precious stones and copper (*2*, *8*, *10*) could not be moved without unloading at Dilmun. The architectural features and other Bronze Age and Dilmun materials on Failaka Island support that it shared institutional aspects with the main Dilmun center (*5*, *11*, *12*). It was the heyday of the Dilmun realm because they were able to strengthen their political influence and their economy by controlling the Arabian Gulf trade network. The growth of the Barbar Temple II (ca. 2025 BC) and the Saar settlement on the mainland of Dilmun (Bahrain) in the late third and early second millennium coincided with the rise of Failaka Island's Dilmun settlements (Tell F3, F6 and Al-Khidr). Archaeological evidence

that supports the latter includes ceramic assemblages, Dilmun stamp seals, architectural details, metal tools, and faunal and floral evidence. The presence of Barbar-tradition pottery or ridged red ware and Dilmun seals were very common on Failaka, indicating colonizing of Failaka by Dilmunites.
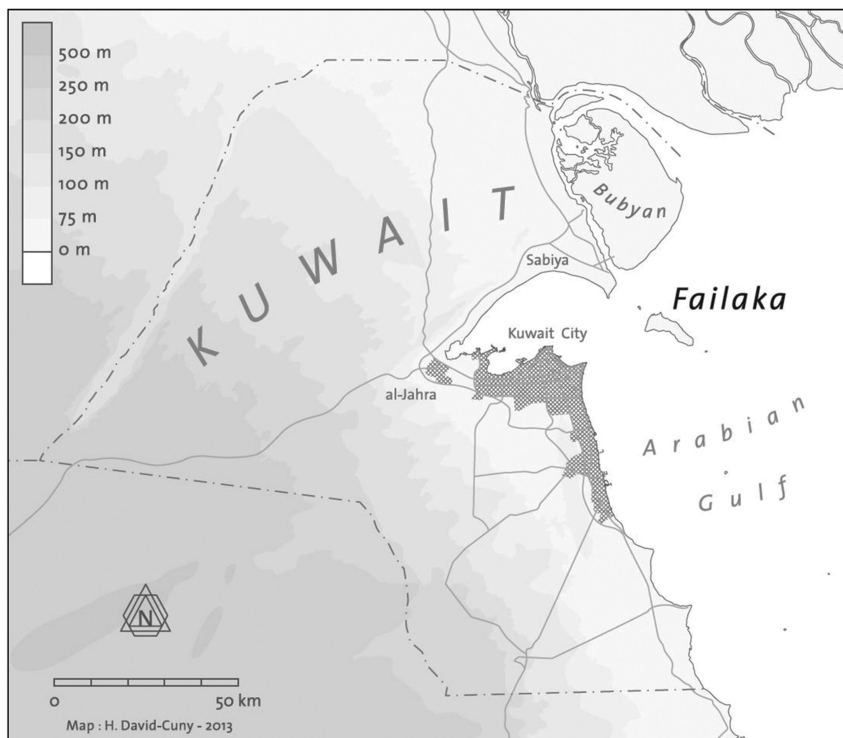

Figure 2. Map of Kuwait and the location of Failaka Island, as the first stop point in the mouth of Shatt al Arab. (Drawing by Hélèn David-Cuny).

Dilmun was seemingly a semi-peripheral entity under the Akkadian empire, but began to emerge as the Akkadians declined. With a lack of discernable military force, it is presumable that Dilmun's emergence and power was expressed culturally. The presence of Dilmun materials can be used to explore how that influence was built. Provenance studies have been used to discuss mechanisms that lend to increased cultural presence, influence, and power of an elite as well as administrative authority. The control of raw materials, craft specialization, standardization of products, and the dissemination of standardized products can be used as indicators of an emerging elite. The need of a new institution, ruler, or governmental personnel was necessary to manage the distribution and production different classes of goods, staple and wealth finance (*13*). In addition to controlling wealth goods, increasing social complexity and emerging elite

and institution could have been in conjunction with staple finance resources. During the Uruk period (ca. 3900-3100 BC), Stein (*14*) noted the control of craft specialists, the standardization of wheel-made pottery, and the wide distribution of utilitarian vessels by temple administrators in ancient Mesopotamia. The staple finance system model was used to discuss how the elite distributed these standardized wares throughout the region. We seek to establish that the mechanism of the rise of a new Dilmun elite in the second millennium was through control of standardized Barbar red-ridge wares. Also, Failaka Island elites or rulers might have sought to enhance their power and prestige through the possession of non-local and far-distance staple and wealth production and through specialized ceramic production.

Dilmun Pottery: Household and Professional Craft Production

The shift of pottery-making in Dilmun from pre-Barbar to the Barbar Period is a crucial key to understand the evolution of ceramic production and Bronze Age craft specialization. Højlund has suggested that pottery-making during the pre-Barbar period in the third millennium at the Qala'at site was exclusively hand-made, with irregularity and unevenness in the rim, nick, and body regions (*3*). The study of remains from the Qala'at site and their development is indeed important as archaeologists consider the site as the capital of Dilmun (*15*). Thus, studying the development of pottery production at Qala'at is one of the crucial windows to understand the scale of labor, specialization and distribution. As mentioned above, the Period I or pre-Barbar period (2150-2050 BC) is known for the chain-ridged pottery type (*16*). Period 1 pottery is tempered with sand and yellowish-white carbonate particles. The color of Period 1 pottery varies from red, light brown to gray, with application of a slip to the outer surface. It is known as Ware Type 1, which is the only ware type found at Qala'at in Period 1. It seems Period 1 pottery was produced at a household level while all of the decorated wares seem to have been imported (*1*, *3*).

During Barbar Period II in the 2nd millennium, use of the wheel technique increases in the Qala'at site and imitation of imported goblets was introduced, indicating the gradual improvements and changes in Dilmun pottery (*3*). The wheel-turntable pottery has a limited number of styles and small luxury production, suggesting craft specialization and standardization in production (*3*). In the Barbar Period (2050-1800 BC), the red-ridged ware, a Barbar type, became widespread in Bahrain and local pottery production had increased compared to a decrease in Mesopotamian pottery and disappearance of southeastern (Umm an-Nar) pottery types (*1*, *3*, *16*). New shapes of pottery were developed in this period and other shapes became much more dominant (*3*). The Barbar Period wares were hand-made, red-brownish, and hard-fired, with yellowish slip covering the outer surface. Painted pottery was introduced in this period, both local and imported, particularly the 'Eastern Tradition' wares from Iran and the Indus Valley (*1*, *3*, *16*). The very distinctive Barbar type wares have been found on Failaka Island, representing a wide range of Barbar ware, including vessels, neck or neckless ridged jars, plates, goblets, bowls, and cooking pots. The Barbar Period II pottery, particularly the IIb phase (ca. 1950 BC), is parallel

In Archaeological Chemistry VIII; Armitage, R., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

to pottery of Barbar Temple Period IIb and Failaka pottery Period 1. The pottery production of this period is continuous with Barbar Period IIa in general with such commonality in wheel-made pottery for the large jars, indicating an improvement in the skills (*3*).

The standardized nature of the pottery strongly suggests that this was mass-produced by professionals, and had shifted gradually from a household level of pottery production (*3*). The shift in ceramic craft production was parallel with increasing social structure and sociopolitical complexity. By the Barbar Period, a fortification wall was achieved in the Qala'at site and an architectural unit of houses at the Saar settlement in Bahrain is also recognized, which shows more in common with the settlement in Tell F3 on Failaka Island (*3*). This period is characterized by the appearance of temples in Bahrain (e.g. Barbar, Saar, Diraz, as-Sujur), and Tell F6 on Failaka Island.

Therefore, we have examined Dilmun ceramics from Failaka Island sites to determine if standardized production recipes were used for Barbar wares. We are suggesting that Dilmun elites controlled the production and distribution of Barbar wares to support their emerging socio-political authority. Specifically, this paper examines the chemical composition of Dilmun ceramic sherds from Failaka Island sites using a non-destructive portable X-ray fluorescence spectrometer (pXRF). Our assumption is that the analytical instrument is able to separate and distinguish ceramic samples within the Tell F6 that comprises the palace-like complex and the Temple. They are the oldest Bronze Age sites on the Island and coincide with the Barbar II period on Bahrain (ca. 2050 BC.). The chemical components can reveal possible standardization of Barbar pottery. Also, the presentation of compositional similarities and differences would also shed light on the extent of Dilmun power over Failaka in terms of craft specialization and distribution. Any chemical separation between the Barbar tradition pottery from Kuwait and Bahrain would suggest that the compositional choice and recipe of each Dilmun center could be differentiated, though there is the standardized appearance (e.g., ridge style).

Toward Archaeometry in the Arabian Gulf

For over thirty years, archaeologists have been studying Dilmun Bronze Age ceramics from Kuwait and Bahrain. Initially, scholars worked to build a chronology for the ceramics in the region by describing and categorizing ceramic types (*5*, *11*, *12*). Later, they would attempt to reconstruct trade networks that could account for the presence of materials from different sites in the Persian-Arabian Gulf region while identifying production centers and distribution routes. Their work would demonstrate the importance of addressing trade and exchange along with social complexity in the Bronze Age (*2*, *5*, *10*, *17*). Employing archaeometric techniques to obtain chemical and mineral composition of ceramics would improve our understanding of trade, exchange and interregional interaction in the Persian-Arabian Gulf in the Bronze Age. Various analytical methods have shown their reliability as tools for geochemical studies and for provenance studies in archaeology (*18–20*). For instance, Kenoyer

and his colleagues used isotopic analyses to suggest the mobility of Harappan individuals to Mesopotamia during the third millennium BC (*21*). The results allowed them to discuss the significance of an individual's mobility in the development of a community despite the large-scale interaction and contact between the two state-level societies. Cross-disciplinary collaboration along with the availability of geological source material, advanced instrumentation, and updated software, ceramics can no longer be considered poor indicators for documenting trade and exchange and interregional interaction. With the chemical characterization of ceramics, archaeologists can use the data generated (i.e., origin, zone of production, and distribution and exchange, etc.) to interpret ceramics as meaningful artifacts.

There are a few studies that have employed archaeometric methods on ceramics in the Persian-Arabian Gulf (*22*, *23*). For instance, Sophie Méry (*24–27*) has used petrographic thin sectioning to characterize ceramics and identify fabric types from fourth and third millennium BC sites in Oman and the United Arab Emirates (UAE). She has demonstrated a connection between the latter by comparing Mesopotamian fabrics from Mesopotamia and the Gulf. The petrographic analyses confirmed the presence of Mesopotamian vessels in Eastern Arabia, implying Gulf participation in the larger trade network that included Iran and the Indus Valley.

Provenance studies of Persian-Arabian Gulf wares using instrumental neutron activation analysis and XRF have yielded interesting results. INAA and petrographic thin section analyses were used to analyze foreign jars recovered from the Oman Peninsula. These techniques established the source of the wares and distinguished between zones of production in the Indus Valley and Iran (*22*, *28–30*). Furthermore, XRF analyses have generated elemental composition data about Bronze Age ceramics from Oman, UAE and Mesopotamia (*31*, *32*). The results pointed to a Southern Mesopotamian origin and were able to distinguish chemical outliers with thin sectioning analysis. In Kuwait, XRF has been used to identify the chemical components of Bronze Age glass and ceramics (*33*). The results have demonstrated that the glazed pottery's alkaline nature makes it particular to the site geologically and temporally.

The significance of this research project is to establish a benchmark using the non-destructive portable X-ray fluorescence (pXRF) technique for the study of Bronze Age ceramics in the Arabian Gulf, particularly Kuwait and Bahrain. Besides constructing a database for the chemical components of Failaka Island and Bahrain ceramics, this study also explores the ancient trade and exchange networks that included Failaka ceramics. The determination of the chemical composition of the second-millennium wares is not only a means of exploring their origin, but also other issues surrounding power and status, such as the accessibility of exotic or prestige items, the expression of status amongst Failaka individuals with such items, and socio-political power and trade. The results obtained are useful for understanding the extent of the Dilmun center's power on pottery production.

Sampling and Analytical Method

Sampling Procedure

The samples analyzed in this study consist of 75 ceramic sherds from various types of early Bronze Age pottery on Failaka Island and Bahrain (Table I). A total of 66 potsherds were taken from Tell F6 in the southwest of Failaka that consists of three sites: the Palace, Trench E, and the Temple (Figure 3). Among 66 sherds, a total of 16 were taken from the palace-like feature known as the Governor's Palace. The samples were taken from the earliest phase known as Failaka Period 1, circa 1950 BC, recovered during the 1960s excavation (*2*). Tell F6, consisting of the Governor's Palace and the Temple, is considered a Dilmun site based on architecture and remnants similar to contemporary Dilmun sites in the Kingdom of Bahrain.

Table I. Summary of sample materials from Kuwait and Bahrain

Site	Structure	Region	Sample Size	Phase
Tell F6	The Palace	Failaka Island, Kuwait	16	Period 1
Tell F6	Trench E	Failaka Island, Kuwait	34	Period 1
Tell F6	Mesopotamian House	Failaka Island, Kuwait	16	Pre-Period 1
Barbar	Barbar Temple	Bahrain	9	Period IIb
			Total 75	

A total of 34 samples were taken from a new trench (Trench E), which lies between the Governor's Palace and the Temple in Tell F6. This trench was excavated during the Kuwaiti-Danish mission of 2009 to determine if there was a connection between the palace and the temple (*34*). All ceramic potsherds selected for this study from Tell F6 are affiliated typologically with the Dilmun tradition and parallel to phase Failaka Period 1 in the Palace, with a few unknown and unusual types found at the site.

During 2008-09 the Kuwaiti-Danish excavation at the Temple in Tell F6, Mesopotamian ceramics were unearthed from a trench. This trench is a stone-built corner of a house embedded in a settlement layer with quantities of animal bones, fragments of bitumen, and Mesopotamian pottery (*34*). Among numerous sherds uncovered, 16 rim and body sherds were selected for this study and marked as a Mesopotamian House collection.

In addition to Failaka Island potsherds, a total of 9 come from the Barbar Temple II in Bahrain (Figure 4). The samples were taken from the IIb phase that is contemporary and parallel with earliest phase in Failaka, Period 1 (1950 BC). The Barbar Temple is located in the village of Barbar in north Bahrain and is the

best preserved of the three Barbar temples. The sacrificial court, shrines and altars suggest that cult ceremonies took place in the temple.
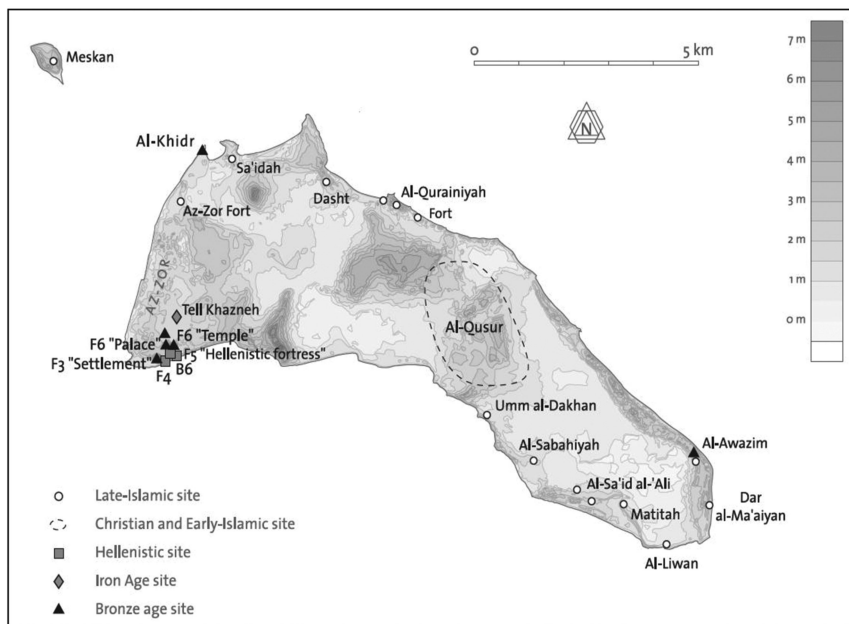

Figure 3. Maps showing various archaeological sites on Failaka Island and the location of tell F6 in southwest of the Island. (Drawing by Hélèn David-Cuny).
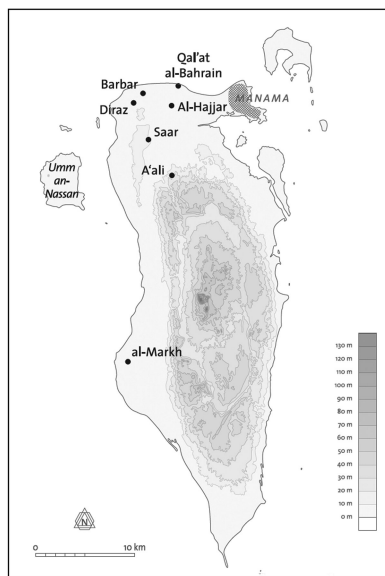

Figure 4. Map of Bronze Age sites in Bahrain and the Barbar village in the north. (Drawing by Hélèn David-Cuny).

Because this paper seeks to possibly fingerprint production centers, we attempt to use well-dated ceramic sherds representing various geographical regions. The goal is to find the possibility of using other ceramic sherds from different regions as a reference for clay and geological features. There is a lack of a database containing information on clay and geochemical data from Bahrain and Kuwait, particularly studies on clay and minerals. In our study, we used Bronze Age ceramic potsherds from Barbar Temple in Bahrain as a reference collection of Bahrain geology and Mesopotamian House potsherds on Failaka Island, Kuwait, as a reference of Iraq clay. Using pottery as a reference has been useful in cases of Aegean archaeology and ceramic studies. The chemical composition of archaeological ceramics of unknown origin is usually compared to ceramics of known origin, or control groups (*35*). The pottery of a control group is established from ceramic materials whose provenance is known or sherds are found in kilns. Arabian Gulf ceramicists are able to identify the provenance of pottery based on typology, temper and sherd fabric, and mass distribution (*3*, *7*, *12*).

Analytical Method

The samples were brushed to remove debris and dirt from excavation and museum storage, and then washed and allowed to dry. After the cleaning of the potsherds, the elemental composition of the surface was analyzed non-destructively using a Bruker Tracer III-SD portable X-ray fluorescence spectrometer. The instrument was set up with a filter (12 mm Al, 1 mm Ti, 6 mm Cu) designed to enhance data measurements of mid-Z elements in the spectrum, while settings of 40 kV and 11 μA were selected to maximize trace element analysis. Only seven trace elements were measured and quantified as they show in our preliminary study their contribution for quantitative analysis including barium (Ba), niobium (Nb), rubidium (Rb), yttrium (Y), strontium (Sr), zirconium (Zr), and thorium (Th). They have been shown in many studies to be successful in determining sources and subsources of ceramic materials (*36–38*). Two major elements, manganese (Mn) and iron (Fe) were excluded due to fluctuation in the measurements, or values below the limits of detection determined in our preliminarily results.

Calibration was conducted on the raw data using a program originally designed for obsidian and other silicate materials. Recently, Speakman and his colleagues (*36*) show that using this calibration for quantifying ceramic data for sherds from the American Southwest worked quite well with potential relative accuracy for calibration. Thus, the data obtained by pXRF in this study is valid for the purpose of the current study, and may be re-calibrated in the future with other software for comparison with other studies.

Each sample was set on the top of the exit window for 120 seconds to obtain elemental composition in parts per million (ppm) concentrations. The ceramic fragments tested are approximately 1-3 cm, and completely cover the beam size of this instrument, which is about 3x5 mm diameter. Because there is some concern about analyzing pottery that does not have a smooth flat surface and thus affecting the actual X-ray angle, the sherd's spot of X-ray exposure has been carefully selected, avoiding a non-flat area and visual temper inclusions. The inner and

outer surfaces of the samples were analyzed and the edges as well for thick samples to overcome the potentially poor representativeness of non-homogenized samples and to ensure that the results are consistent. Our preliminary results showed that the multiple runs on different positions within the whole sample are consistent. Hence, the data value used for each sample is the average of the measurements at different positions.

pXRF Performance

Though it is still considered a new technique in archaeological studies, pXRF has been employed in the last decade for identification and characterization of ancient metals (*39*), gold and silver jewels (*40*), and obsidian tools (*19*, *41*, *42*). A few studies have employed pXRF on ceramics (*43–45*), while most archaeologists have employed INAA, ICP, and laboratory XRF for clay sourcing to address trade and exchange issues. There has been a reluctance to use this handheld instrument for provenance studies on ceramics because of the inherent complexity of ceramics as well as the sensitivity and precision of the commercial instrument. Because this study is the first of its kind in the Arabian Gulf, we first asked, how effective would the pXRF be for chemical characterization? The heterogeneous nature of ceramics leads archaeologists to use more reliable and accurate analytical instruments that require cutting the ceramics and powdering the sample for dissolution or pelletization procedures. In our case, the potsherd samples had to be returned and the pXRF instrument allowed us to avoid the destruction of the sample that other analyses require.

In our preliminary study, we selected three Bronze Age ceramic potsherd samples from Failaka island to compare chemical compositions obtained from pXRF with the results from one of the most accurate instruments, inductively coupled mass-spectrometry (ICP-MS), at the University of South Florida's Center for Geochemical Research. According to the scatterplot, the database yields from ICP-MS are closely aligned with the composition obtained using pXRF (*46*). They correlate rather well with the exception of Sr that has a partition coefficient larger than 1 in plagioclase and smaller than 1 in clay minerals, so the results yielded from pXRF have to be carefully interpreted for the bulk composition. Overall, the results show the great potential of pXRF for quantitative analyses of ceramic sherds from Failaka Island. The portable XRF application is valuable especially in the study of the Arabian Gulf region because it can be used to establish a chemical database without compromising the integrity of ceramic collections. The instrument has also been shown to be useful in grouping Bronze Age clay cuneiform tablets from Hattuša, Turkey, and el Amarna, Egypt (*47*).

Technically, the pXRF instrument has shown that it is a reliable tool non-destructively, and by using empirical calibration for chemical characterization of ceramics. Speakman et al. (*36*) has demonstrated the value of the pXRF technique on ceramics from the American southwestern region. Additionally, the latter results from the pXRF instrument were comparable to the results obtained from INAA even though INAA is considered more precise (*36*). By generating a dataset that employed both pXRF and ICP-MS for Failaka sherds, this study used

the same approach. The ability of pXRF as a method to measure trace elements effectively and distinguish compositional groups of heterogeneous material is vital to ceramic analysis for the Arabian Gulf region trade network.

Multivariate Statistical Analyses

It is useful to employ multivariate statistics to find which elements can be informative to differentiate ceramic groups. However, we began with simple scatterplots to show variations in chemical composition between samples even if they are not distinguishable visually. A simple scatterplot of trace elements Rb, Sr, and Y shows differentiation between and within sites. The trace elements Rb, Sr and Y suggest a different composition within the Trench E site and the Barbar Temple of Bahrain (Figure 5), and one sample from Barbar Temple of Bahrain and one from Trench E on Failaka are clustered with the Mesopotamian House's samples. Also, one sample from Trench E is clustered alone in the top of the plot as an outlier as well as one from Barbar Temple. The presence of Rb, Sr and Y confirms the variation within and between the four archaeological sites, with a potential small group consisting of a few sherds from the Palace and the Mesopotamian House.
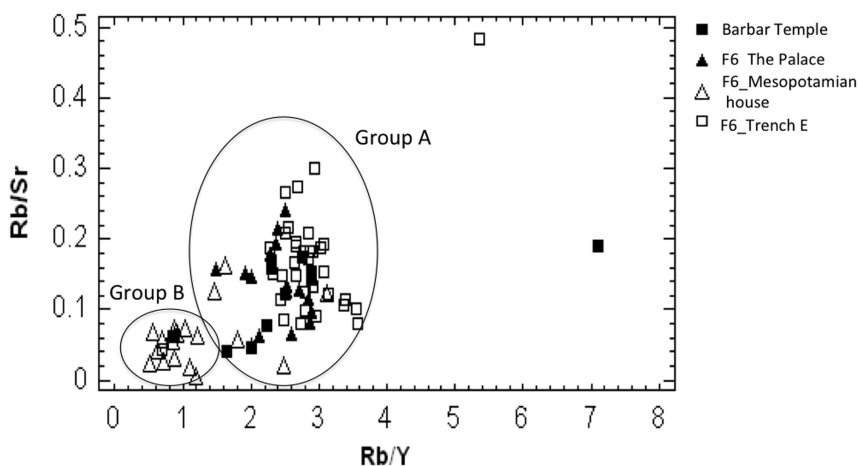

Figure 5. Plot of the Bronze Age ceramics from Kuwait and Bahrain from four sites showing variation within Failaka Island sites, two distinct groups of ceramics (Dilmun sites vs. Mesopotamian House), and a potential separation within the F6 site, showing a few sherds clustering in a small group.

Principal Component Analysis

A variety of statistical applications were employed to evaluate the data collected using SPSS statistical software. Principal component analysis (PCA) is an exploratory method to examine the correlation between chemical elements and suggest which variables or groups of elements are meaningful and can account

for the maximum variance in the data set. Transformation of the dataset into logarithms has been performed to standardize the data. The SPSS component matrix is useful because it contains the loading of each variable onto each factor. The results also show that the values of the first three components explain 79% of the variance.

A scatterplot was performed using PCA scores 2 and 3 that include Nb, Th, Sr, Y, Zr, Rb, and Ba, which previously showed their high contribution in the component matrix. The results show two distinct groups of ceramics (Figure 6), while the Palace, Trench E and Barbar Temple are clustered together (group A). It also shows a distinct group of samples including the Mesopotamian House with a few outliers from the Barbar Temple and Trench E (group B). There are two outliers from the Palace; one is sitting noticeably as an outlier. The PCA results show the separation of sherd samples between and within the archaeological sites.
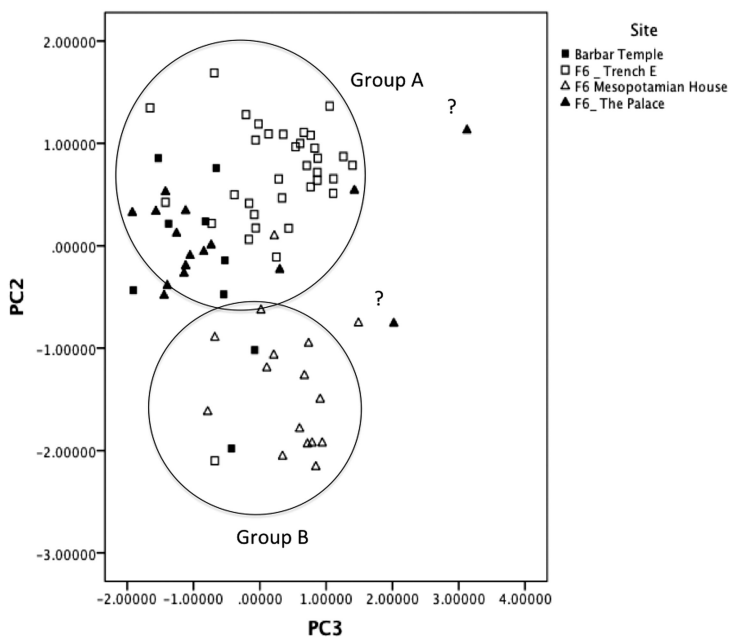

Figure 6. Biplot derived from principal component analysis of 75 sherd samples measured by portable XRF.

Cluster Analysis

The principal component analysis is followed by a cluster analysis using PCA scores, which include all 7 elements (Nb, Th, Sr, Y, Zr, Rb, and Ba), for identifying natural groupings and evaluating PCA results. K-means cluster analysis was utilized for the clustering method because it groups all samples and then finds clusters. K-means cluster analysis is useful to test our research questions about the presence of more than two groups of ceramic sherds, as it

can explore the number of groups. The ANOVA output is the most important aspect in cluster analysis in order to see which factor is great and statistically significant (.000). ANOVA results show that all PCA factor scores are statistically significant, while the PCA scatterplot used in Figure 6 shows how PCA factors are useful for grouping our samples.

Discriminant Function Analysis

Discriminant function analysis (DFA) was employed as a different statistical technique to discriminate between groups and classify our samples into different production centers. We assume that there are four production centers that the samples might have been made at: Dilmun, Mesopotamia, Indus Valley, and Iranian plateau. We used original log data for all seven elements (Nb, Th, Sr, Y, Zr, Rb, and Ba) as variables and site names as a grouping variable. The canonical discriminant function plot shows that the ceramic sherds are separated into two main groups, with a potential small group (Figure 7). It shows a group of Mesopotamian House with two samples overlapping from other sites, and a big cluster includes the Barbar Temple site of Bahrain, the Palace site and the Trench E site on Failaka Island. The Wilk's output shows that the three discriminant functions are statistically significant (p < .000).
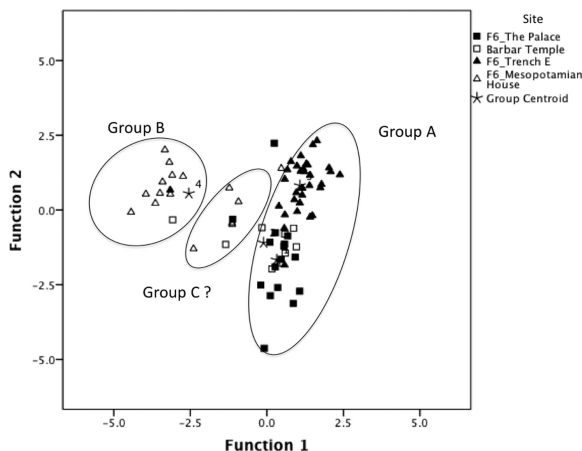

Figure 7. Biplot based on canonical discriminant functions showing two distinct groups (A, B). The small cluster (group C) is a mix from three sites.

Discriminant function analysis also produces a number of scores as PCA factor scores. Thus, a scatterplot was performed using discriminant scores on the discriminant axes (DF1, DF3) as seen in Figure 8. Ceramic potsherds are grouped into two main groups. Those groups that formed the big cluster (group A) come from the Barbar Temple, the Palace, and Trench E, with one overlapping

sample from the Mesopotamian House. Group B consists of samples from the Mesopotamian House on Failaka Island and the overlapping two samples from Trench E and the Barbar Temple of Bahrain. Group C has four outliers from the Palace site and finally group D is clustered in the middle of the scatterplot that consists of mixed specimens from the Barbar temple (No. 13662) and four from the Mesopotamian House on Failaka Island. This group of ceramic sherds obviously appeared in the discriminant analysis more than in the former analyses. Based on statistics, 81.3% of the original grouped cases are correctly classified.
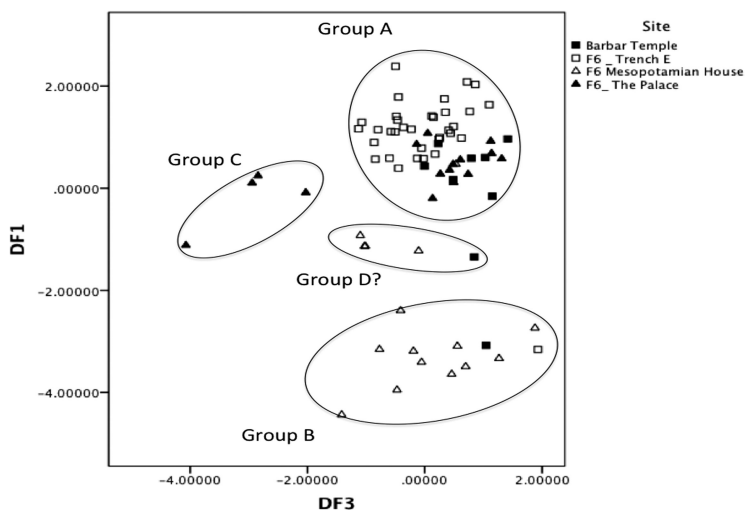

Figure 8. Biplot of discriminant scores on discriminant function 1 and 3 showing a mixed pattern of Dilmun specimens from three sites on Failaka and Bahrain (group A), along with a well-separated group of the Mesopotamian House (group B). Note that a few specimens from the Palace were combined based on discriminant scores (group C).

Results and Discussion

The statistical results performed on Bronze Age ceramics from Kuwait and Bahrain show a pattern of four distinctive groups. Ceramic potsherds from group A are from Barbar Temple of Bahrain, and the Palace and Trench E from the Tell F6 site on Failaka Island (see Figure 9). Group A has a large amount of ceramic artifacts comprised of large red-ridged jars as well as smaller slipped reddish sherds. They have the ridged reddish slipped feature typical for the Bronze Age Dilmun or Barbar pottery type. This type of pottery can be further divided into groups based on color, grain size, and hardness. The Barbar type ceramic artifacts are fired, hand-made, and the colors are homogenous. The first type of this reddish ware is the well-fired ware strongly tempered with sand and white-yellowish lime particles, known as A-ware in the Barbar ware category (*12*). In the center of these particles is a hollow area, seen as irregular rounded spots, which probably arose

from firing lime (*12*). The second type is also well-fired but not harder than the A-ware type. It is medium-tempered with finer particles. The core is yellowish red to reddish brown with a gray or red slip. It is known as the C-ware type in the Barbar ware category (*12*). Within group A, there is a sample (No. 15163) that came from the Mesopotamian House of the Tell F6 site that overlaps with the Barbar ceramic group. Based on its red color, slip, and incised lines, it is diagnostic of Period 3A ceramics on Failaka (Højlund, pers. com.). The Period 3A (1720 –1550 BC) piece could have been deposited later into the Mesopotamian House feature during the rebuilding or restoring of the Temple on top of the Mesopotamian house structure.

Ceramic potsherds of group B were highly tempered with fine material. The sand particles are seldom seen, while the colors range from pale brownish and pale greenish to light gray (see Figure 10). It has a surface of fine texture and smooth clay, while some have straw impressions (G-ware type). The G-ware group was known for being wheel-made, except for the giant storage vessels, and belongs to the Mesopotamian tradition (*12*). They are two- and three-rib rim sherds corresponding to Ur III type 1 vessels. They came from the lowest level of the Temple at F6, which belongs to the Mesopotamian House. It represents the Third Dynasty of Ur or Ur III occupation horizon (2100-2000 BC) that pre-dates the establishment of the Dilmun colony on Failaka Island (*48*).

Within group B, one sample (No. 13661), which came from the Barbar Temple of Bahrain, is overlapping with the Mesopotamian sherds (see Figure 10C). It was assumed to be of the Barbar tradition, but it falls within the Mesopotamian group. Texturally speaking, it is wheel-made and has green to gray color on the outer and inner surfaces. This product might have come to Bahrain during the Isin-Larsa dynasty in Mesopotamian that ruled the south portion from 2000 to 1760 BC. Also, one sample (No. 15137) came from Trench E that represents the early Dilmun occupation level, 2000-1900 BC. It was assumed to be an imported sherd (*49*). Features like its greenish color and inside ridge along with our results support its Mesopotamian tradition (see Figure 10D).

Figure 9. Group A samples consisting of Dilmun sherds comprising large red-slipped and smaller reddish sherds.
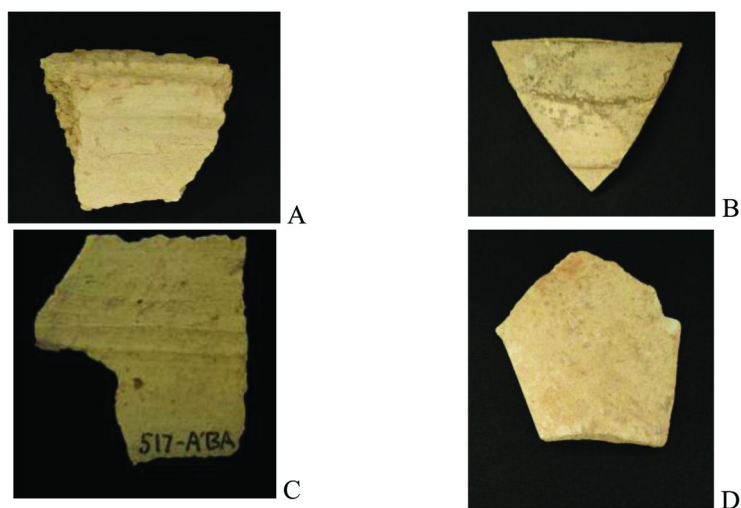
Figure 10. Group B samples consisting of Mesopotamian tradition sherds as their colors range from pale greenish to pale gray found in the Mesopotamian House in the F6 tell (A, B). pXRF and statistical analyses confirming the one sample from Barbar Temple (C) and one specimen from Trench E of Failaka (D) as being of Mesopotamian origin.

Ceramic sherds of group C consist of four samples that came from the Palace of the Tell F6 site on Failaka Island. Three sherds are a reddish color, have a hard clay body, and are wheel-made (see Figure 11) which indicates that they are an Indus Valley type (*49*). It had been assumed that sample No. 13618 is of the Dilmun tradition, but statistically it falls within the Indus sherds group; it has a very smooth surface and is made of hard clay. The other probable explanation is the movement of Indus potters into the Persian/Arabian Gulf who added some Dilmun stylistic elements on the red hard-clay ceramics. One sherd is red ware with whitish slip, covered with yellowish particles as the A-ware type. Pores are clearly seen in the inner surface besides a few whitish-yellowish hollows, but are bigger than A-ware type sherds in group A. It is possible that the outer and inner pores that arose either from lime particles or clay paste due to firing temperature could effectively influence the absorption of X-rays, giving inaccurate results that exclude the sherd from the Barbar wares in group A.

The last potential group of ceramic sherds is group D (see Figure 12), clustered in the middle of discriminant function plot (see Figure 8) and previously mixed with group C in canonical discriminant functions (see Figure 7). They are red-brown in color, have a hard-clay body, smooth outer surface and no visible inclusions. Three of them have been assumed to be Mesopotamian reddish sherds and one as an unknown import. The absence of porosity and the treatment might suggest distinct red-sherd pottery production within the Mesopotamian territory. The one unknown import (15158) might be a sub-group of Mesopotamian pottery. The Eastern Province origin of this sherd also would be a question of interest. Statistically speaking, these Mesopotamia sherds suggest that potters might have

used specific clay and temper, in addition to the well-known greenish-gray and reddish pottery. Therefore, we recommend obtaining more clay or sherd samples from the Eastern Province of Saudi Arabia, Mesopotamia, and the Indus Valley to look for similarities and possibly identify the production center of this group of samples.

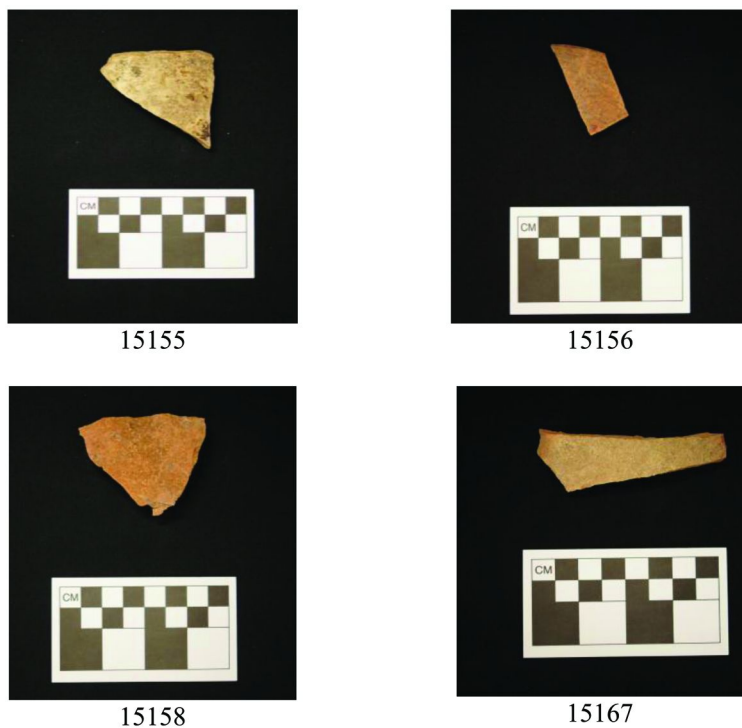*Figure 11. Group C consisting of hard reddish and fine clay specimens indicating their Indus Valley type.*

15155

15156

15158

15167

Figure 12. Group D clustering specimens that might have been imported from far-distant region or subgroup of Dilmun or Mesopotamian pottery.

Conclusion

In this paper, we have demonstrated that pXRF can contribute valuable data to construct a database for chemical components of ceramic pottery wares recovered from Failaka Island and Bahrain. Technically, this initial analysis shows the success of pXRF for examining the homogeneity of a sample, identifying unknown samples, and testing previously assumed origins for samples. The pXRF device is a reliable tool to fingerprint or at least create compositional groups for the production center and recognize ceramic centers that stylistic and descriptive methods can confuse. More data is recommended to be selected for more analysis by other analytical instruments, creating empirical calibration for Arabian Gulf ceramics. This would allow other researchers to use the data in the future for comparison.

Statistically, the principal component and cluster analyses successfully differentiated the samples based upon their elemental compositions and were confirmed by discriminant function analysis. The PCA shows a similar chemical compositional profile for Dilmun ceramics from Kuwait and Bahrain, suggesting a centralization of ceramic production and standardized raw materials during the early second millennium BC. The PCA and discriminant analyses show that the Dilmun sherds from the Palace and Trench E in Tell F6 on Failaka Island have the same compositional pattern as those from the Barbar Temple of Bahrain indicating that both ceramics were made of the same raw material. Whatever the treatment of the outer surface for the Dilmun vessels, the choice of using locally available raw materials is noticeable.

Moreover, it is reasonable that Dilmun sites in Bahrain might be the ceramics' production center and the source of ceramics flowing to Failaka Island in Kuwait, considering the archaeological absence of firing kilns for pottery on Failaka Island. Around 2050 BC, Barbar ceramic production grew, indicating a gradual shift from household production to a professional craft production; this shift coincides with the emergence of complex sociocultural elements such as religious monuments, temples at Barbar of Bahrain and the F6 Temple on Failaka Island, fortified stone walls, and local-style stamp seals (*3*, *5*). Thus, it is reasonable by 1950 BC to find more Barbar sherds (period IIb) and these are similar to Failaka Period 1 sherds. The Barbar IIb period is crucial for the Dilmun administration particularly after the collapse of the Ur III dynasty in Mesopotamia. In this period, Dilmun seems to be one of the main suppliers to the Mesopotamian market and to be an active partner with Babylonian merchants (*5*). Thus, the appearance of Mesopotamian sherds in Trench E (earliest Dilmun horizon on Failaka) and at the Barbar Temple is reasonable to reflect this interregional interaction. With more evidence and further study, this dramatic change in Dilmun could push Dilmunites to move to Failaka and create the first social formation to ensure its northern border and enhance the trading relationship with Mesopotamia (*5*). Interestingly, Barbar Temple samples show the usefulness of using the Bahrain collection as a reference group of clay sources and geochemical data, despite the small size of samples selected for this study. However, petrographic thin-section analysis is highly recommended in the future to determine the source of chemical components and mineralogical variation and the influence of behavioral or natural parameters in the composition.

The similarity in chemical composition between one of the samples from Trench E on Failaka and Barbar Temple in Bahrain sherds with greenish sherds from the Mesopotamian House suggests the use of the same raw material; the Mesopotamian House sherds from the Tell F6 site are useful as a group reference for Mesopotamian geology, or at least for Mesopotamian origin. The Mesopotamian house sherds infer the Ur III expansion in the Arabian Gulf. It is documented that under the Ur III rulers, Mesopotamian merchants established a connection with suppliers of copper, particularly with Magan/Oman. The claim of Ur-Namma (2113-2095 BC) referred to the establishment of trade with Magan during his reign, copper in exchange for textiles (*39*). Numbers of Type 1 of Ur III vessels discovered in Dilmun mounds in Bahrain support the long-distance trade and exchange between Ur III and Magan that might have been placed by highly organized institutions (*48*). With this recent discovery of the Mesopotamian structure supported by chemical analysis, Failaka seems under control of the Ur III, as one of those harbors and refueling centers along the trading routes, during the end of the third millennium BC.

The results suggest that not only did Dilmun have standardization of raw materials, but so did other trading polities, such as the Indus Valley and Mesopotamia. The raw materials that lent to the production of Barbar wares are consistent. Also, the hard-clay reddish sample from the Palace is clustered rather well with the appearance of other Indus valley sherds. The presence of Indus valley sherds, particularly from the Palace site, suggests that the residents of the palace or the governor's house of the Tell F6 site on Failaka Island had access to non-local materials, particularly imported ceramics.

Standardization of ceramics can be used to reconstruct interregional interaction, trade and exchange. The control of raw materials available to craft specialists and the imposition of the types of raw materials to be used in production can be traced with the pXRF device. Elites, emerging or established, can exert parameters through close relationships with their native craftsmen to control the types of goods and commodities that circulate within a larger trade network for the good of the larger society (*50*). The presence of Indus valley sherds as exotic items would support our assumption about how elites or rulers controlled the accessibility and distribution of non-local wares, and even their participation in the long-distance, external network to the exclusion of others on the island. The residents of the Palace site on Failaka seemingly sought to take advantage of the prominence of the Dilmun state (mainland center) and its dominance over the Arabian Gulf trade network. Undoubtedly, understating the role of elites or rulers and sociopolitical institutions as well as craft specialization in Dilmun requires more ceramic materials and analyses to shed light on the scale and level of ceramics and other staple finance productions.

This interregional interaction did not start with the establishment of a Dilmun colony on Failaka as we have seen from evidence in the lowest level of Trench E at Tell F6. Even during the pre-Dilmun period, at the Ur III period house on Failaka Island we have seen evidence of an interregional contact. Failaka Island probably seemed a proper transit point or port for the Ur III dynastic authorities because it lies at its southern border. The presence of late third-millennium Mesopotamian sherds, 2nd millennium Dilmun, and Indus type sherds on Failaka

Island support our notions of the power of the political economic institutions. We think these institutions controlled long-distance trade and interregional exchange between different cultural entities on a large scale, and this control and activity increasingly contributed to the emergence of social complexity and economic structure, particularly within the Dilmun entity. The development of sociopolitical power in Dilmun is characterized by the presence of mound burials, Dilmun stamp seals, Barbar ridged ware, and temple complexes as well as establishing a trading port as seen on Failaka Island during the Bronze Age. The craft specialization, particularly pottery production and the control of raw materials, is of interest to understand the practice of sociopolitical and economic power within the Dilmun realm.

Acknowledgments

References

1. Crawford, H. *Dilmun and Its Gulf Neighbours*; Cambridge University Press: Cambridge, U.K., 1998.
2. Weisgerber, G. In *Bahrain through the Ages: The Archaeology*; Al Khalifa, H., Rice, M., Eds.; KPI: London, 1986; pp 135−142.
3. Højlund, F.; Anderson, H. *Qala'at al-Bahrain 1. The Northern City Wall and the Islamic Fortress*; Aarhus University Press: Aarhus, Denmark, 1994.
4. Benedikova, L. *Al-Khidr 2004-2009; Primary Scientific Report on the Activities of the Kuwait-Slovak Archaeological Mission*; NCCAL: Kuwait City, 2010.
5. Højlund, F. *The Burial Mounds of Bahrain: Social complexity in Early Dilmun*; *Jutland* Archaeological Society: Moesgård, Denmark, 2007.
6. Ratnagar, S. *Trading Encounters from Euphrates to the Indus in the Bronze Age*; Oxford University Press: New Delhi, India, 2004.
7. Larsen, C. *Life and Land Use on the Bahrain Islands: The Geoarcheology of an Ancient Society*; The University of Chicago Press: Chicago, IL, 1983.
8. Cleuziou, S. In *Bahrain through the Ages the Archaeology*; Al Khalifa, H., Rice, M., Eds.; KPI: London,1986; pp 143−155.

9. Zarins, J. In *Bahrain through the Ages the Archaeology*; Al Khalifa, H., Rice, M., Eds.; KPI: London,1986; pp 233−250.
10. Potts, D. In *Bahrain through the Ages the Archaeology*; Al Khalifa, H., Rice, M., Eds.; KPI: London,1986; pp 389−398.
11. Højlund, F. In *Bahrain through the Ages the Archaeology*; Al Khalifa, H., Rice, M., Eds.; KPI: London,1986; pp 217−224.
12. Højlund, F., Ed.; *Failaka/Dilmun: The Second Millennium Settlements; Volume 2: The Bronze Age Pottery*; Aarhus University Press: Arhus, Denmark, 1987.
13. Brumfield, E.; Earle, T., Eds.; *Specialization, Exchange, and Complex Societies*; Cambridge University Press: London, 1987; pp 1−9.
14. Stein, G. In *Craft Specialization and Social Evolution*; Wailes, B., Ed.; University Museum Monograph 93; University of Pennsylvania Museum: Philadelphia, 1996; pp 25−38.
15. Højlund F. In *Bahrain: The Civilisation of the Two Seas*; Lombard, P., al-Sindi, K., Eds.; Institute du Monde Arabe: Paris, 1999; pp 73−76
16. Larsen, C. *Life and Land Use on the Bahrain Islands: The Geoarcheology of an Ancient Society*; University of Chicago Press, Chicago, IL, 1983.
17. Edens, C. *Am. Anthrop.* **1992**, *94*, 118–139.
18. Chen, T.; Rapp, G. R.; Jing, Z. C.; He, N. *J. Archaeol. Sci.* **1999**, *26*, 1003–1015.
19. Tykot, R. H. *Acc. Chem. Res.* **2002**, *35*, 618–627.
20. Munita, C. S.; Paiva, R. P.; Alves, M. A.; Oliverira De, P. M.; Momose, E. F. *J. Radioanal. Nucl. Chem.* **2001**, *248*, 93–96.
21. Kenoyer, J. M.; Price, T. D.; Burton, J. H. *J. Archaeol. Sci.* **2013**, *40*, 2286–2297.
22. Blackman, M. J.; Méry, S.; Wright, R. P. *J. Field Archaeol.* **1989**, *16*, 61–77.
23. Mynors, H. S. *Proceedings of the 22nd Symposium of Archaeometry*; Schools of Physics and Archaeological Science, University of Bradford: Bradford, U.K., 1983; pp 377−387.
24. Méry, S. *Paléorient* **1991**, *17*, 51–78.
25. Méry, S. *Annali Istituto Universitario Orientale* **1995**, *55*, 193–206.
26. Méry, S. *Les ceʹramiques d'Oman et l'Asie moyenne: Une archeʹologie des eʹchanges aʹl'Aˆ ge du Bronze*; CNRS: Paris, 2000.
27. Méry, S. In *The Shadow of the Ancestors: The Prehistoric Foundations of The Early Arabian Civilization in Oman*; Cleuziou, S., Tosi, M., Eds.; Ministry of Heritage and Culture: Oman, 2007; pp 199−201.
28. Méry, S.; Blackman, M. In *Harappan Studies 3*; Lecture, World Archaeology Conference, New Delhi, India; pp 1−32.
29. Méry, S.; Blackman, M. J. *Paléorient* **1999**, *25*, 167–177.
30. Méry, S.; Blackman M. J.; Didier, A. In *Proceedings of the Seminar for Arabia Studies*; Oxford University Press: Oxford, U.K., 2012; Vol. 42, pp 195−204.
31. Méry, S.; Schneider, G. In *Proceedings of the Seminar for Arabia Studies*; Oxford University Press: Oxford, U.K., 1996; Vol. 26, pp 79−95.

32. Méry, S.; Schneider, G. In *Etudes mésopotamiennes. Recueil de textes offert à J.-L. Huot*; Breniquet, C.; Kempinski-Lecomte, C., Eds.; Bibliothèque de la Délégation Archéologique Française en Iraq 9: Paris, 2001; pp 263−275.

33. Pollard, A. M. In *Failaka/Dilmun: The Second Millennium Settlements; Volume 2: The Bronze Age Pottery*; Højlund, F., Ed.; Aarhus University Press: Arhus, Denmark, 1987; pp 185−189.

34. Højlund, F. *Arab. Arch. Epig.* **2012**, 165–173.

35. Day, P.; E. Kiriatzi, A.; Tsolakidou, A.; Kilikoglou, V. *J. Archaeol. Sci.* **1999**, *26*, 1025–1036.

36. Speakman, R. J.; Little, N. C.; Creel, D.; Miller, M. R.; Iñañez, J. G. *J. Archaeol. Sci.* **2011**, *38*, 3483–3496.

37. Goodale, N.; Bailey, D.; Jones, G.; Prescott, C.; Scholz, E.; Stagliano, N.; Lewis, C. *J. Archaeol. Sci.* **2012**, *39*, 875–883.

38. Hoeck, V.; Ionescu, C.; Ghergari, L.; Precup, C. *Geologia* **2009**, *54*, 41–51.

39. Astour, M. In *Eblaitica*; Gordon, C., Rendsburg, G., Eds.; Eisenbrauns: Winona Lake, IN, 2002; pp 57−196.

40. Karydas, A. K.; Kotzamani, D.; Bernard, R.; Barrandon, J. N.; Zarkadas, C. *Nucl. Instrum. Methods B* **2004**, *226*, 15–28.

41. Shackley, S. *Obsidian: Geology and Archaeology in the North American Southwest*; University of Arizona Press; Tucson, AZ, 2005.

42. Craig, N.; Speakman, R. J.; Popelka-Filcoff, R. S.; Glascock, M. D.; Robertson, J. D.; Shackley, M. S.; Aldenderfer, M. *J. Archaeol. Sci.* **2007**, *34*, 2012–2024.

43. Liritzis, I.; Drakonaki, S.; Vafiadou, A.; Sampson, A.; Boutsika, T. In *The Neolithic Settlement at Ftelia, Mykonos*; Sampson, A., Ed.; University of the Aegean: Greece, 2002; pp 251−272.

44. Papadopoulou, D. N.; Zachariadis, G. A.; Anthemidis, A. N.; Tsirliganis, N. C.; Stratis, J. A. *Talanta* **2006**, *68*, 1692–1699.

45. Papagrotgiou, I.; Liritzis, I. *Archaeometry* **2007**, *49*, 795–813.

46. Cirpian, S; Ashkanani, H; Tykot, R. H.; Puscas, M. *Proceedings of the 39th International Symposium for Archaeometry, Leuven*, 2013, in press.

47. Goren, Y.; Mommsen, H.; Klinger, J. *J. Archaeol. Sci.* **2011**, *38*, 684–696.

48. Laursen, S. *Arab. Arch. Epig.* **2011**, *22*, 32–47.

49. Højlund, F. Personal communication; Moesgård Museum, Aarhus, Denmark, 2011.

50. Hirth, K. *J. Archaeol. Res.* **1996**, *4*, 203–2301996.