

## Trace-Element Analyses of Near Eastern Ceramics:

### A Re-Evaluation of the Uruk Expansion and Interregional Ceramic Exchange in the Late 4<sup>th</sup> Millennium BC

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Leah Minc

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*OSU Archaeometry Lab  
100 Radiation Center  
Oregon State University  
Corvallis, OR 97331*

## PROJECT BACKGROUND

Ceramic provenance studies work by comparison: we need good reference materials in order to identify local vs. non-local material, and to match a ceramic vessel to its place of origin. As Steven Shackley has stated so well: “Nothing is ever really ‘sourced’. The best we can do is provide a chemical characterization and a probable fit to known source data” (1998:261).

The present set of studies was motivated by the need to build-up a comparative data base of ceramic pastes for the Near East. In spite of the critical insights which chemical analyses can provide for studies of inter-regional exchange, relatively few characterization studies have been carried out on Near Eastern ceramics (Alden *et al.* n.d., Berman 1986; Blackman 1981, 1985, 1988, 2003, 2011; Emberling *et al.* n.d., Ghazal *et al.* 2008; Henrickson and Blackman 1992; Thuesen and Heydorn 1990), and these represent a limited number of ceramic wares, sites, and chronological periods. Our goals were (1) to dramatically expand the spatial scope of ceramic trace-element data for the region to include major sites and culture areas, and (2) to begin using these data to directly address models of regional economic and political organization, inter-regional interaction, and changes in these patterns through time.

With the support of NSF and participating museums, we have completed trace-element analyses and photo-documentation of nearly 1700 ceramic samples (Table 1), from key sites stretching across Syria, Iraq, Iran, and western Pakistan (Fig. 1). As a group, these analysis will provide physical evidence allowing researchers to examine economic interactions between the lowlands of greater Mesopotamia, the highlands of the Iranian plateau, and along the inter-montane valleys of the Zagros mountains. The present report, however, focuses on a subset of these samples: those directly involved in the question of the Uruk Expansion.

### The Uruk Expansion

During the mid-4th millennium BC, the material culture of southern Mesopotamia begins to appear in southwestern Iran, northeastern Syria, and southern Turkey (Algaze 1989, 2005; Rothman 2001; Schwartz 2001; Stein 1996). The southern material includes sand-tempered ceramics in distinctive forms and surface treatments as well as administrative technology (seals, tokens, numerical tablets) and architectural patterns. In his path-breaking discussions of this phenomenon, Guillermo Algaze (1989, 2004, 2005) argued that the expansion represented an attempt to gain control of raw materials and trade routes, through the establishment of trading enclaves and outposts along key routes to the uplands. He suggested that high-value goods such as copper, gold, silver, lead, lapis lazuli, and alabaster, as well as more mundane tree products and limestone were shipped down river. In exchange, Algaze (2005:74-75) suggests that Mesopotamia exported perishables, including textiles and possibly bulk grain, as well as liquids such as oil, wine, honey, and perhaps a fermented salt fish sauce similar to the Roman *garum*. Thus, it is tempting to see much of the Uruk-style pottery (particularly jars and bottles) as containers for these exports from Mesopotamia, and to interpret their presence in outlying areas as reflecting a substantial movement of goods and commodities between regions. Possible alternatives to exchange, however, include colonies of refugees fleeing conflict or political instability in Mesopotamia (Johnson 1989), acculturation resulting from long-term contact between adjacent regions, or perhaps emulation of S. Mesopotamia by local elites attempting to increase their status (Stein 1996).

Our sampling strategy was designed to rigorously evaluate the extent of ceramic exchange between the Uruk heartland and apparent Uruk settlements outside the core, by establishing the provenance of Uruk-style vessels dating to the Late Uruk (3700-3100 BCE). Our sample targets three different types of

Uruk settlements: (1) the Mesopotamian heartland and adjacent Susiana Plain; (2) apparent Uruk colonies, such as the intrusive southern-style presence at Tell Brak and Jebel Aruda in northeast Syria; and (3) Uruk outposts. At each site, we have attempted to sample a range of grit-tempered vessel forms, including carinated “nose lug” jars, spouted “torpedo” jars, strap- and twist- handled jars, fine ware jars, as well as mass-produced bowls and larger storage jars that would presumably define local clays for the region. Descriptions of each collection follow.

**Table 1.** INAA Sample for the Near East

<b>Site/Region</b>	<b>Project ID</b>	<b>Loaning Institution</b>	<b>Sample</b>
Mesopotamia	RC1901	Oriental Institute, Chicago	91
Tell Brak	RC1883	University of Michigan	75+21
Jebel Aruda	RC1941	Dutch Natl. Museum of Antiquities	76
Tell Hadidi	RC1989	Milwaukee Public Museum	36
Tell Humeida	RC1959	Universidade da Coruña	10
Nineveh	RC1960	British Museum	21
Godin Tepe	RC1959	Royal Ontario Museum	86
Kunji Cave	RC1987	University of Michigan	95
<b>Susiana Plain</b>			
Abu Fanduweh	RC1845	Oriental Institute, Chicago	27
Khuzistan clays	RC1845	Oriental Institute, Chicago	9
Susa		Private	3
<b>Ram Hormuz Plain</b>			
Tal-e Geser	RC1938	Oriental Institute, Chicago	77
<b>Mamasani Survey</b>	RC1988	University of Cambridge	100
<b>Kur River Valley</b>			
Late Banesh-Malyan	RC1845	Oriental Institute, Chicago	17
Sumner Survey	RC1911	Penn Museum	550
Ring scrapers (RS)	RC1911	Private	27
<b>Iranian Plateau</b>			
Yanik Tepe	RC1902	University College of London	12
Tepe Hissar	RC1912	Penn Museum	64
Sang-e Chakmaq	RC1912	Penn Museum	17
<b>Eastern Iran-Pakistan</b>			
Tal-I Iblis	RC1937	University of Georgia	26
Tepe Yahya	RC1959	Harvard Peabody Museum	123+102
Shahr-i Sokhta	RC1940	Palazzo Brancaccio & ISAO, Rome	91
Bampur	RC1959	Harvard Peabody Museum	8
Makran	RC1959	Harvard Peabody Museum	14

## Sample Data Sets

**Mesopotamia.** In order to characterize Late Uruk ceramics from the Mesopotamian heartland, we drew on survey collections from southern and central Mesopotamia curated by the Oriental Institute of Chicago. Specifically, we utilized material from the Warka (WS) and Akkad (AS) surveys directed by Robert Adams (Adams and Nissen 1972; Adams 1981). Geoff Emberling and Henry Wright selected 91 samples that reflect the diversity of classic Late Uruk forms. These include a variety of bottles and conical and droop-spout jars; small jars with nose-lugs and bands of cross-hatch incision (CHBJ) on the shoulder, globular storage jars with diagonal reserve-slip, hammerhead-rim bowls, and heavy ledge-rim jars.

**Susiana Plain.** Geographically, the Susiana Plain represents an eastward extension, at a slightly higher elevation, of the alluvial plains of Mesopotamia, and provides important connections both to the central plateau of Iran to the North and to the Ram Hormuz plain to the SW. By Middle/Late Uruk times, this region had become part and parcel of the Mesopotamian world, an extension eastward of the culture and institutions prevalent in the lowlands of S. Iraq (Algaze 2005: 13). Ceramic assemblages are nearly identical between the regions, and there are conspicuous similarities in glyptic practices, accounting procedures (tokens, balls, bullae and tablets) and iconography, and monumental and religious architecture. Further, the material culture is clearly homogenous across the plain, with Mesopotamian traits present from the largest centers to smaller sites. Algaze (2005:14) interprets this similarity to indicate that "Susiana was culturally as much a part of the Mesopotamian world as the alluvium itself", either through long-term interaction or colonization.

For comparative material from the Susiana Plain, we are very fortunate to be able to draw on analyses of mid-4th millennium pottery conducted by Royal Ghazal (Ghazal *et al.* 2008) working in collaboration with the archaeometry team at MURR. Their Late Uruk sample focused on two types – the chaff-tempered BRBs and the grit-tempered CHBJs -- utilizing collections now housed at the Oriental Institute and the University of Michigan. By Late Uruk times, the Susiana Plain was divided into an western region under Susa, and an eastern region under Choga Mish, with a 15-km wide no-man's land in between (Johnson 1975). The Ghazal-MURR sample comes primarily from two large sites in the NE, Choga Mish (Alizadeh 1985) and Tepe Sharafabad, with a small sample from Abu Fanduweh located in the SW Susiana Plain. We supplemented their study with additional ceramics (N=27) from Abu Fanduweh, selected by Abbas Alizadeh.

**Tell Brak.** Located in northeastern Syria along the Khabur River, Tell Brak is one of the largest sites in northern Mesopotamia, covering an area of about 40 hectares and rising to a height of over 40 meters. The site has been the focus of excavations since Mallowan (1947) uncovered the famous Eye Temple in the 1930s. Extensive excavations by David and Joan Oates, Roger Matthews, Geoff Emberling, and most recently Augusta McMahon (Oates and Oates 1993, 1994, 1997; J. Oates 2002; Emberling *et al.* 1999, 2002) have documented a long and complex history of construction and occupation.

For our purposes, the important findings come from the large sounding in Area TW, in which a series of *in situ* deposits spanning the 4th millennium were encountered. These document a long, indigenous Late Chalcolithic sequence at the site (Levels 20-14), with initial contact and exchange with S. Mesopotamia in the later part of the Middle Uruk period (Level 13). The subsequent Late Uruk levels (Levels 11-12), however, reveal a marked cultural discontinuity. The assemblage is

entirely S. Mesopotamian in style including Uruk-style architecture (including the use of riemchen bricks), ceramics, glyptic, and complex tokens. Emberling (2002) further argues that the Eye Temple was remodeled at this time, with the 4th and last structure built and decorated to include features of Mesopotamian origin (Mallowan 1947). The conclusion is that Uruk elements thoroughly replaced the local material culture and architectural traditions over a sizable portion of the site, suggesting that S. Mesopotamian populations intruded into the area during the Late Uruk, establishing some sort of colony. The site is well positioned to control overland N-S traffic from the Tigris to Anatolia, and Algaze suggests that the intrusion of a S. Mesopotamian presence there was aimed at exploiting highland resources for the alluvial market (Algaze 2005:46).

Our sample of Late Uruk ceramics from the University of Michigan are drawn from Levels 11-12 of the TW unit. They feature classic Late Uruk forms, such as bottles, CHBJ, jars with nose-lugs, diagonal reserve slip, and droop spouts. It is also noteworthy that the pastes are nearly identical to those found in S. Mesopotamia, generally buff in color with angular white and gray grit temper.

**Jebel Aruda.** Located along the upper Euphrates in northern Syria, the large site of Jebel Aruda has similarly been interpreted as an Uruk colony, although one founded on virgin ground. At a distance of over 800 km from southern Mesopotamia, the architecture and material culture are identical to that of the Uruk heartland, and present a very compelling case for a southern Mesopotamian presence in the area (van Driel 2002). Excavations at Jebel Aruda were conducted in the late 1970s by the University of Leiden, as part of salvage operations preceding the construction of the Tabqa Dam. Extensive collections of this material are currently housed in the Dutch National Museum of Antiquities (Rijksmuseum van Oudheden), Leiden. Collaborators Henry Wright and Geoff Emberling traveled to the Netherlands to document and select samples from Jebel Aruda, and nip off small samples for chemical and residue analysis. (Because the Jebel Aruda collections technically belong to the Syrian government, it was not possible for the Leiden museum to ship sherds to us for analysis.) Vessel forms include classic Uruk markers, including bottles, jars with cross-hatch band incision, nose-lugs, and droop spouts, as well as bevel-rim bowls and wall-cones. Unfortunately, no ceramics of “local” Chalcolithic style are available from the site.

**Tell Hadidi.** Located just across the Euphrates from Jebel Aruda, Tell Hadidi offered the opportunity to establish a compositional signature for ceramics definitively produced along the Upper Euphrates. International rescue operations were begun at the site in 1973-1974 by a Dutch team, and continued between 1974 and 1978 under the direction of Rudolph Dornemann, then of the Milwaukee Public Museum (Dornemann 1979, 1988, 1992). Much of the site has since been submerged by the artificial lake formed behind the Tabqa Dam.

Tell Hadidi was an important urban center during the 3rd-2nd millennia BC, and this era is represented by clear evidence of ceramic production. Exposed in Area F, it includes the remains of a kiln and a downslope scatter of charcoal, ash, and large sherds - some warped and over fired - interpreted as “wasters that were rejected by the potters after having been misfired in the kiln” (Mason and Cooper 1999:136). Petrographic analysis of 33 sherds from Area F (including strata not associated with the kiln) concluded that the bulk of the pastes represent variations of local Euphrates’ sediments (Mason and Cooper 1999). These ceramics are thus linked to local Euphrates clay by their production context, style, and mineralogy, and provide an invaluable indication of the chemical composition of Syrian (vs. Mesopotamian) ceramics.

In addition, Dornemann's excavations encountered a small amount of Middle-Late Uruk ceramics

at the site (Area R), which would be contemporaneous with Jebel Aruda, or possibly slightly predate the establishment of that Uruk colony. Courtesy of the Milwaukee Public Museum, we have analyzed 36 vessels from Tell Hadidi, including 24 sherds previously analyzed via ceramic petrography and 12 examples of Middle-Late Uruk pottery.

**Nineveh.** Although less well known, Nineveh represents another potential Uruk enclave on the Upper Tigris, with both architectural and artifactual evidence pointing to a significant Uruk presence at the site (Algaze 2005:37; Campbell Thompson and Mallowan 1933). Located at an important juncture between the main north-south corridor (the Tigris) and major east-west overland routes connecting with the Euphrates, Nineveh would have been an ideal transshipment point where overland traffic from the west could be easily funneled downstream on the Tigris (Algaze 2005: 46-48). Thus, it was highly desirable to sample ceramics from this site: if the presence of Uruk-style ceramics represents an actual trade in ceramic containers, that evidence should be forthcoming at Nineveh.

Collections from Mallowan's 1931-1932 excavations at Nineveh are curated by the British Museum. Although the museum was reluctant to contribute ceramic samples for destructive analysis, permission was finally obtained to sample a small number (N=21) of Uruk-style vessels from Nineveh. Geoff Emberling traveled to London to photograph and record the samples; the British Museum later supplied small pieces of these vessels along with in-house reference materials for INAA. The sample from Nineveh includes classic Uruk forms such as small jars with nose-lugs, punctate and/or appliqued decoration; jars with droop spouts; small bottles; and bevel-rim bowls. (If the data for the reference standards are satisfactory, a further sample of approximately 13 sherds could be made available for analysis this coming year.)

The third prong of our investigation involves the apparent Uruk presence further afield from the Mesopotamian heartland, and includes possible Uruk outposts or trading stations.

**Tepe Godin.** Located in the Kangavar valley of central western Iran, Tepe Godin was excavated by the late T. Cuyler Young Jr. under the auspices of the Royal Ontario Museum and the University of Toronto from 1965 to 1973, and all of the diagnostic ceramic sherds from the excavations are currently stored in the Royal Ontario Museum. Tepe Godin was a locally important site at the time of the Uruk expansion during the fourth millennium BC due to both its size and location (Gopnik and Rothman 2011). At 14-15 hectares, it was the largest site in the area during this time period, and was strategically located along a major east-west trade route - the High Road - that eventually linked the Mediterranean and the Far East.

In the latter half of the fourth millennium BCE (Godin VI), evidence for contact with Uruk sites to the south comes from the intriguing "Oval Compound" (Gopnik and Rothman 2009:85-105). This thick-walled structure has been interpreted as a gate-house or possible fort protecting trade routes in the area, especially those funneling goods to the lowlands. Within the Oval Compound, excavators encountered tablets and seals, as well as substantial quantities of classic Uruk forms, including bevel-rim bowls, nose-lug jars, droop spouts, bottles, and string-cut bases typical of Uruk wheel-throwing technique (Gopnik and Rothman 2011:90), which contrast with the local ceramic traditions. Prior trace-element and petrographic analyses indicate that the local style presents a relatively homogeneous paste composition, with mineral inclusions consistent with the geology of the Kangavar valley (Henrickson 1989). In contrast, the Godin VI samples were apparently manufactured from a number of different clay sources, including some that may be non-local in

origin (Blackman 2011).

Our goal was to significantly expand the sample of Godin VI ceramics - including both local and Uruk-style material - in order to better evaluate the nature of Uruk presence at the site. Collaborators Hilary Gopnik (Emory University) and Clemens Reichel (University of Toronto) therefore selected a total of 66 vessels dating to Godin VI from the ROM collections. These include 31 vessels from inside the Oval Compound, with the remainder representing non-Uruk style pottery from the village. In addition, Gopnik submitted a small sample of Godin II material (Gopnik 2003, 2005) in order to expand the temporal range of ceramics from the site and evaluate continuity in clay use and ceramic technology over time. Both data sets complement earlier trace-element analyses of pottery from the Kangavar Valley (Henrickson and Blackman 1992; Vitali *et al.* 1987).

**Tal-e Geser.** The Ram Hormuz plain lies to the east of Susiana, along one of the major inter-montane transportation routes leading to Elam (Ansham). The site was a regional center for the nomadic tribes that occupied the Ram Hormuz plain, but its role as an interregional trade nexus in the 4th millennium is unknown. In contrast to the pervasive presence of S. Mesopotamian-style architecture, accounting practices, and ceramic materials found in Susiana, Tell Brak, and Jebel Aruda, Late Uruk influence at Tal-e Geser is limited to pottery in typical Late Uruk forms. According to Abbas Alizadeh (pers. comm.), these come either from refuse deposits or on the floor of very insubstantial buildings, and are found mixed with local pottery. The overall assemblage is a complex of utilitarian types, “nothing eye-catching or extraordinary”, and the late Uruk deposits in general are very poor in terms of material. Thus, rather than representing a well-established or high-profile enclave of people from S. Mesopotamia, the Uruk presence at Tal-e Geser might better be interpreted as remains left by local or nomadic peoples who utilized vessels from S. Mesopotamia. Our ceramic sample from Tal-e Geser includes 77 samples ranging in date from the 5<sup>th</sup> through 3<sup>rd</sup> millennia BC.

**Tepe Yahya.** Located in southeastern Iran roughly midway between the great cities of the Mesopotamian plains and those of the Indus Valley, Tepe Yahya provides a unique perspective on possible exchange relations between distant territories. Excavations were conducted at this site from 1968 to 1975 (Lamberg-Karlovsky 1970; Beale and Lamberg-Karlovsky 1986; Potts and Lamberg-Karlovsky 2001), and the collections are now housed within Harvard’s Peabody Museum.

The materials of primary interest to this project are ceramics from Period IVC, currently estimated between 3100 and 2800 BCE, and representing phases immediately following the Uruk Expansion proper. Material culture of Period IVC reveals strong “Western” connections as represented by inscribed tablets, cylinder-seals and sealings (Pittman 2001), and, in terms of ceramics, forms similar to those found at Susa in Khuzistan in Late Uruk/Proto-Elamite periods (Periods II-III), at Tal-i Malyan in Fars in Proto-Elamite/Banesh periods, and in Mesopotamia in Late Uruk/Jemdet-Nasr periods (see Lamberg-Karlovsky 1971, 2009; Potts and Lamberg-Karlovsky 2001; Lebrun 1978; Nicholas 1990; Potts 1999, 2001; Sumner 2003). Shared ceramic attributes include grit- and chaff-tempered wares in the shape of beveled-rim bowls, low-sided trays, carinated bowls, and goblets, as well as impressed, nose-lugged, and spouted jars of the Uruk-style, and jars bearing polychrome paint in the Jemdet-Nasr style of production in Mesopotamia.

As selected by Karl Lamberg-Karlovsky and Benjamin Mutin, our sample from Tepe Yahya includes 68 vessels from Period IVC, including “Western” forms noted above; the remaining 65 represent material from the subsequent IVB phase. Through comparison with materials from SW Iran and

Mesopotamia, it will be possible to determine whether these western-style ceramics found at Tepe Yahya were imported or locally produced.

## **SAMPLE PROCESSING AND ANALYSIS**

**Sample Preparation.** All ceramic samples were analyzed at the OSU Archaeometry Lab. Sherds were first photographed (interior, exterior, profile). A small portion of the sherd (*ca.* 1 x 2 cm) was then cleaned by removing surface pigments and contamination with a tungsten carbide burr or rotary file. This portion was removed, rinsed with de-ionized water and dried, before being pulverized in an agate mortar and pestle. Powdered sherd material was archived in glass scintillation vials. Finally, ceramic pastes were photographed on the fresh break at 50x, 100x, and 200x, using a digital fiberoptic microscope.

**INAA Protocols and Analyses.** All ceramic samples were characterized for a suite of 30 major, minor and trace elements, through a protocol of two neutron irradiations in the OSU TRIGA reactor and multiple counts of gamma activity. To quantify elements with short half-life isotopes, approximately 250 mg of pulverized material was encapsulated in high-purity polyethylene vials, and delivered via pneumatic tube to an in-core location with a nominal thermal neutron flux of  $10^{13} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ . The 7-s irradiation was followed by two separate counts of resultant gamma activity, one after a 15-minute decay (for Al, Ca, Ti, and V) and a second count after 2-hr decay (for Dy, Mn, K, and Na); both counts were for 540 seconds using a 25-30% relative efficiency HPGe detector.

To quantify elements with intermediate and long half-live isotopes, sample materials were subjected to a 14-hr irradiation in the rotating rack of the reactor, a location which experiences a nominal thermal neutron flux of  $2.3 \times 10^{12} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ . Again, two separate counts of gamma activity were acquired, the first count of 5000 s (live-time) began 6 days after the end of irradiation, while the second count for 10000 s followed a 4-week decay. These two counts provided data on As, La, Lu, K, Na, Sm, U, Yb, and Ba, Ce, Co, Cr, Cs, Eu, Fe, Hf, Nd, Rb, Sb, Sc, Ta, Tb, Th, and Zn, respectively. Element concentrations were determined via the direct comparison method; three replicates of the standard reference material NIST1633a (coal fly ash) and one of NIST688 (basalt) were utilized as standards. All data reductions were based on current consensus element libraries utilized by the Missouri University Research Reactor for archaeological materials (Glascock 1992, 2006).

**Statistical Analysis.** Quantitative analyses of the resultant trace-element data followed now standard procedures for group identification and verification, including (1) preliminary identification of compositional groups using bivariate plots, (2) group refinement to create statistically homogeneous core groups using the multivariate Mahalanobis distance measure, and (3) classification of non-core members into their most likely compositional group using discriminant analysis and multivariate distance measures.

Each site was first examined individually, and obvious outliers and subgroups were noted. The goal was to identify a “main” group for each site since, according to the principle of local abundance, the most prevalent group represents local manufacture. All preliminary groups so defined were then checked for internal homogeneity using a jack-knifed Mahalanobis distance measure. In this test, also called “leave-one-out”, each case is removed one at a time and then statistically compared against the group composed of the remaining samples. If the group is homogeneous, the removal of a single sample will have minimal impact on its location and spread, and the jack-knifed case will have a high probability of membership in the remaining group. Samples with low probabilities of



group membership are removed until a coherent composition group is attained. The resultant composition groups (or reference groups) are then compared against all other groups, to check for possible overlap. Finally, individual samples of unknown provenance are tested for membership in the established groups, the assumption being that a high probability of membership reflects a match in composition and a common geographic origin.

Multivariate statistical evaluation of composition groups can be severely limited by small group size: the rule of thumb suggests that group membership should be at least three times that of the number of variables (or elements) used in the analysis. When this rule is violated, groups can become expansive or overly inclusive of dissimilar members, as group structure (based on inter-element correlations) is underspecified. Thus, principle components analysis is often used to reduce the dimensionality of the data set and provide a new set of axes (components) for group evaluation and testing. These components represent weighted linear combinations of the elements, and are extracted to account for strong inter-element correlations or covariances representing major dimensions of geochemical variability.

In a robust PCA of all Near Eastern ceramics based on the inter-element correlation matrix (excluding the most variable 5% as determined through multivariate distance measures), the first five components have eigenvalues  $> 1$  and account for 82% of the variance (Table 2). The first component (53%) shows a positive correlation with Al and a negative correlation with Ca, and reflects a dilution effect by calcium on most other elements. The second component reflects the contribution of the trace metals Fe, Cr, Mn, and Co, while the third component largely reflects Na vs. K content. The fourth and fifth components are less straight-forward in their geochemical interpretation, and involve Mn, Ba, and As, and K-Zn, respectively.

In this complex data set, PCA illustrates major inter-group differences, but tends to obscure subtle differences among groups; thus, PCA is used for illustrative purposes only. Instead, preliminary group assessment was based on 8 elements (Al, Ca, Na, Sc, Cr, Mn, La, Th) identified through step-wise discriminant analysis as providing excellent group separation at the regional level. Where sample sizes permitted, reference group refinement and membership assessment were based on the full set of elements.

**Establishing Provenance: Issues of Scale and Uniqueness.** Ceramics can be challenging to source. In theory, geologic parent material and depositional history combine to create a unique trace-element signature for a given clay deposit. In actuality, it is rarely so simple. Potting clays are the end product of extensive weathering, erosion, and redeposition of sediments which can blur the uniqueness of a clay source signature across the landscape. Thus, alluvial deposits along major rivers such as the Tigris or Euphrates may be broadly similar for a considerable distance, reflecting their shared source materials upstream. Conversely, a complex geology can create highly similar clays in spatially distinct areas. For example, the Southern foothills of the Zagros consist of folded Precambrian-to-Pliocene shelf sediments 8-10 km thick; the predominate parent materials for clay formation throughout this region (marl, limestone, shale, siltstone, and/or sandstone) occur as discontinuous bands of similar composition running NW-SE for a hundreds of kilometers (Fig. 2, from Haghypour 2009). In both of these scenarios, there is no clear relationship between geographic proximity and geochemical similarity.

**Table 2.** Robust Principle Components Analysis of Near Eastern Ceramics

Number	1.000	2.000	3.000	4.000	5.000
Eigenvalue	14.234	3.530	1.680	1.403	1.184
Percent	52.718	13.073	6.221	5.195	4.385
Cum. Percent	52.718	65.791	72.013	77.208	81.592
Total structure coefficients:					
Al	<b>0.937</b>	0.050	-0.077	-0.054	0.101
Ca	<b>-0.634</b>	-0.019	<b>-0.539</b>	0.201	0.322
K	0.442	<b>-0.448</b>	0.295	0.229	<b>-0.453</b>
Na	-0.302	0.346	<b>0.707</b>	-0.068	0.032
Fe	<b>0.784</b>	<b>0.541</b>	-0.121	0.002	0.018
Ti	<b>0.843</b>	0.177	-0.313	-0.142	-0.001
Sc	<b>0.796</b>	0.482	-0.164	-0.134	0.019
V	<b>0.812</b>	0.276	-0.212	-0.079	-0.053
Cr	-0.067	<b>0.789</b>	0.279	-0.272	-0.064
Mn	-0.062	<b>0.630</b>	-0.123	<b>0.613</b>	0.117
Co	0.280	<b>0.897</b>	0.042	0.093	-0.112
Zn	0.357	-0.068	-0.314	0.311	<b>-0.638</b>
Rb	<b>0.772</b>	-0.256	0.266	0.135	-0.260
Cs	<b>0.806</b>	-0.319	0.063	-0.132	0.061
Ba	0.317	0.147	0.341	<b>0.419</b>	0.310
As	0.319	-0.093	0.116	<b>0.687</b>	0.095
La	<b>0.950</b>	-0.225	-0.056	-0.013	0.059
Ce	<b>0.949</b>	-0.234	-0.068	-0.016	0.049
Sm	<b>0.967</b>	-0.026	-0.045	-0.008	0.005
Eu	<b>0.932</b>	0.169	-0.133	-0.013	0.001
Tb	<b>0.763</b>	0.183	0.075	0.071	0.066
Yb	<b>0.914</b>	0.134	0.137	-0.006	0.083
Lu	<b>0.916</b>	0.049	0.121	-0.058	0.078
Hf	<b>0.883</b>	-0.106	0.216	-0.092	0.053
Ta	<b>0.870</b>	-0.174	-0.247	-0.029	0.029
Th	<b>0.917</b>	-0.208	0.188	0.024	0.072
U	0.384	<b>-0.527</b>	0.074	0.039	<b>0.463</b>

As a result, improbable matches should be treated with caution: there might well be a much closer source of clay that is an equally good match. To return to the quote from Steven Shackley (1998), the best we can do is provide a probable fit to known source data. As our knowledge of sources expands, provenance determinations may need to be reconsidered.

## RESULTS: Establishing Reference Groups

Reference groups have been established for most areas and collections examined, including Mesopotamia, the Syro-Tigridian highlands, the Susiana Plain, various valleys within the Zagros foothills, and far SE Iran. In the following sections, each reference group is defined in a series of bivariate plots, and its average composition compared with neighboring regions across a profile of 27 elements. Element values were first normalized by dividing by the grand mean for all ceramics, in order to put all elements on a common scale. Element values were then ordered and plotted by

geochemical group (major elements, transition metals, alkali elements, rare-earth elements, and high field-strength incompatibles), so that differences in the ratios of key elements can be readily evaluated.

**Mesopotamia.** The ceramic samples from the Warka and Akkad surveys form a relatively coherent group with few outliers (Fig. 3). There are no strong differences between samples from southern and central Mesopotamia and hereafter these are considered as a single reference group. Relative to other regions (Fig. 4), Mesopotamia is about average on the first principle component (Al:Ca ratios), but relatively high on the second principle component, suggesting somewhat enriched values of the trace metals chromium, manganese and cobalt (Fig. 5). Surprisingly, Mesopotamia is only slightly enriched in sodium content relative to other regions.

**Upper Euphrates.** The ceramics from our sites along the Upper Euphrates have ceramics very similar in composition to those of lower Mesopotamia. Almost all the samples from Jebel Aruda fall within the reference group for Mesopotamia (Fig. 6) and have significant probabilities of membership within the Mesopotamian ceramic group. Our immediate question was whether this represented a substantial trade between Mesopotamia and this Uruk colony (across a distance of more than 800 km upriver), or whether the clays in the two regions were strongly similar, again in spite of a separating distance of more than 800 km and differences in geology along their drainages. The sample from Tell Hadidi favors the second alternative. Ceramic production debris from Tell Hadidi is also very similar to ceramics from Mesopotamia (Figs 7 and 8.), with only slight differences in sodium and potassium, which could reflect differences in weathering of sediments (Fig. 9). Given this similarity, our working assumption is that clays along the Euphrates form a single “source”; accordingly, we have combined clays from the Upper and Lower Euphrates into a single reference group for interregional comparisons.

**Susiana.** The prior work of Ghazal *et al.* (2008) on Uruk ceramics from Susiana indicated that there are clear differences among the products of ceramic-producing sites within the Susiana Plain. Specifically, they illustrate that the ceramics of the northern sites Tepe Sharafabad and Choga Mish could be readily separated based on bivariate plots of tantalum and thorium (Fig. 10), while the more southerly Abu Fanduweh differs in having higher concentrations of the first series transition metals, particularly chromium, but lower calcium (Fig. 11). In our broader regional perspective, however, the differences between Tepe Sharafabad and Choga Mish are relatively subtle. For example, these sites are virtually identical based on the first two principle components, and overlap significantly on the third. In terms of tracking inter-regional interaction, we therefore suggest that the two sites can be safely combined into a single N. Susiana reference group, which contrasts with the more internally variable (and expansive) reference group from Abu Fanduweh. (Note that Abu Fanduweh partially overlaps Mesopotamia on the first two principle components, but not on the third, and therefore has been omitted from bivariate plots of principle components.)

**Tell Brak.** The Uruk-style ceramics from Tell Brak form an internally consistent and coherent group, with no evidence of subdivisions (Fig. 12). As a reference group, Tell Brak presents a fairly average composition, and occupies a central location on principle component axes. Tell Brak differs from Mesopotamia in lower trace-metal content (see Fig. 5), and from Susiana in higher rare-earth element (REE) content. Only two sherds from the site are obvious outliers, and probably non-local in origin.

**Tepe Godin.** The sample from Tepe Godin contains three discernable composition groups and several outliers (Fig. 13). Only the Godin Main group was sufficiently large to refine with multivariate analysis; it contains the bulk of the samples (N=64), and presumably represents local ceramic manufacture. Two sherds from Upper Kiln Lot 12 (GOT\_029 and GOT\_041) fall in the Godin Main composition group and further strengthen this conclusion. The Godin Main group, which includes ceramics from both the Uruk and Median occupations, is distinguished by low concentrations of calcium, but elevated concentrations of the alkali elements K, Rb, and Cs, as well as the rare-earth element suite and thorium (Fig. 14). Godin-2 (N=7), which similarly contains both Uruk and Median ceramics, shares the low Cr:Mn ratios with Godin Main, but is otherwise less extreme. Godin-3 consists of three samples of Uruk date with very low Ca:Al ratios, elevated concentrations of the first-series transition metal suite, and heavy rare-earth (HREE) anomaly. Finally, the Godin assemblage contains four clear outliers, of which three are of Median date.

The Godin groups are quite distinctive in composition at the regional level (Fig. 15). All three are high in REE concentrations relative to other reference groups discussed so far.

**Nineveh.** Our sample from Nineveh is small and internally variable. There are strong outliers on individual elements (NIN\_08 has extreme values of Cr, while NIN\_03, -07, -11, and -12 have high As), and at least three samples are obvious outliers on the first two principle components (Fig. 16). Minus these obvious outliers, the Nineveh samples appear to form a somewhat coherent group that may be the basis of a regional composition group. The ceramics are quite similar in composition to Tell Brak (Fig. 17), the site's relatively nearby highland neighbor. Our proto-group may well contain imports from that center, as well. Further work clearly needs to be done on this potentially important site.

**Tal-e Geser.** Our assemblage from Tal-e Geser separates into two (or three) main composition groups: Tal-e Geser Main (N=41) and Tal-e Geser Low Mn (N=23), with the latter potentially subdividing into Low and Very Low Mn subgroups. As the name suggests, the Geser Low Mn group differs from the Geser Main group in having low manganese (Mn < 500 ppm) concentrations (Fig. 18), as well as higher average concentrations of aluminum, the rare earth elements, chromium, and hafnium. On many elements, however, the boundary between these two TG groups is not sharp, and they overlap slightly on the primary principal component axes. The Tal-e Geser Main has a close affinity to Abu Fanduweh reference group, and the two overlap strongly in many bi-dimensional plots (Fig. 19). Based on 8-element probabilities of group membership, four samples from Abu Fanduweh join the Tal-e Geser Main, and most TG-Main members show at least a low probability of membership in Abu Fanduweh. On distances calculated on 27 elements, almost all of the Tal-e Geser Main group shows a significant membership in the Abu Fanduweh group, but this may be owing to the fact that the Abu Fanduweh group is small relative to its dimensionality, and so is somewhat expansive. A compositional profile of the two groups illustrates that they are similar but not identical in composition, and we attribute this to similarities in geology between the two regions. Both the Main and Low Mn groups contain ceramics dating from the 5<sup>th</sup> through 3<sup>rd</sup> millennia.

**Kur River Basin (KRB).** The KRB is included here as it provides a link along a major transportation route leading eastward to SE Iran. Because of the time depth and large number of samples we have from the KRB, the material will be treated in greater depth elsewhere. Briefly, the KRB samples are revealing distinctive compositional signatures for several ceramic production centers within the region. For the Banesh period (*ca.* 3200-2600 BCE), we have defined the trace-element signatures for two different manufacturing centers producing High Al grit-tempered ceramics, Tal-e Kureh

and Malyan, as well as a High Cs group found primarily at Malyan.

**Tepe Yahya.** The assemblage from Tepe Yahya is complex and internally quite variable, containing a number of distinct ceramic groups. In order to make sense of this complexity, the ceramics were first divided into chaff vs. grit temper wares. The chaff group consists of 30 vessels, including bevel-rim bowls, carinated bowls, and low sided trays, which exhibit a mix of fiber temper and grit inclusions. These vessels clearly divide into two groups based on Ca:Al ratios (Fig. 20A). Both BRB and trays occur in both High and Low Ca:Al groups, while the carinated bowls are limited to the Low Ca:Al group. The chaff-tempered set also includes two outliers.

Among the 93 grit-tempered vessels (mostly painted jars), four composition groups are noted. The vessels divide first into two main groups based on Co:Fe ratios (Fig. 20B); each of these then subdivides based on Ca:Al ratios (Fig. 21). The High Co:Fe group and its subdivisions closely parallel the chaff-tempered groups defined above, while the Low Co:Fe group and its subdivisions do not. This four-fold division suggests two different clay sources (one calcium-rich and the other not), and two different temper sources that differ in metal content, combined into different paste recipes. The comparison of profiles (Fig. 22) suggests that Low Ca clays are also lower in manganese and somewhat higher in the REE, while the addition of temper not only enriches pastes in cobalt but also reduces sodium content. All of these groups are well represented in the assemblage (Table 3), and are probably local paste recipes, although the Low Ca clays are much more common. Ceramic petrography would greatly assist in sorting this out. Finally, six outliers were encountered in the grit-tempered set.

**Table 3.** Group Sizes for Tepe Yahya

Temper	Low Ca Clay	High Ca Clay
Chaff	19	9
High Co:Fe Grit	28	13
Low Co:Fe Grit	32	14
Total	79	36

### **RESULTS: Assigning Provenance for Apparent Non-Local Samples**

All samples were tested against the reference groups defined above, using the Mahalanobis distance statistic to assess the probability of group membership. Distances were assessed on the subset of 8 best-discriminating variables or, for the larger reference groups, based on the full suite of 27 elements. In addition, possible matches were visually assessed by examining the compositional profile of the case in question relative to the reference groups.

**Mesopotamia.** Six outliers (ca. 7% of the sample) appear to be of non-local origin (Fig. 23). Five bevel-rim bowls (URUK\_079, -080, -085, -087, and -089) have significant probabilities of group membership in the Abu Fanduweh reference group, whether measured across 8 or the full suite of 27 elements; these are also assigned to Abu Fanduweh by discriminant analysis (Fig. 24 and Fig. 25). URUK\_040 (a red-paste jar) is distinctively different from Mesopotamia, and is variously assigned to other low Ca, Low Mn groups, including the Tal-e Geser Low Mn, Low Ca subgroup or Tepe Yahya

Main (Fig. 26 and 27); its true provenance remains undetermined.

**Jebel Aruda.** Only three samples appear to be of non-local origin: JEB\_041, -042, and -043; all are large jars from the same provenience (Fig. 28). These samples have no probability of belonging to the Mesopotamia reference group, whether measured across 8 or the full suite of 27 elements, and clearly separate from the Jebel Aruda samples in principle component or discriminant analyses space. Unfortunately, all these samples are clear outliers on one or more elements (Fig. 29), and thus do not display clear membership in any of the defined reference groups. JEB\_041 has extreme Ba content, JEB\_042 extreme Ba and As content, while JEB\_043 has extreme Cr and high Co content.

**Tell Hadidi.** Eight samples from Tell Hadidi are clear outliers to the local Upper Euphrates/Mesopotamia composition group (Fig. 30); six of these had been identified as non-local pastes based on ceramic petrography (Mason and Cooper 1999). None of the 2<sup>nd</sup> millennium BC outliers (HDD\_03, -08, -10, -11, -24, and -27) show a significant probability of group membership in any of the defined reference groups. Within the corpus of 4<sup>th</sup> millennium vessels, HP\_8360 (a sun-dried tile or brick) has fairly high concentrations of calcium, which (along with unburned organic matter) may be diluting other elements in what is essentially a Mesopotamian paste (Fig 31). HP\_5735 (a simple cooking pot) is most similar to Tell Brak, and is assigned to that group by discriminant and cluster analyses; it has a low probability of membership in the Tell Brak reference group as determined across 27 elements.

**Tell Brak.** Only two samples from Tell Brak are clear outliers, TBK\_048 and TBK\_068. Both have high Cr:Ca ratios, a good marker of Mesopotamian ceramics, and although neither have a significant probability of membership in that reference group, both show a generic similarity to Mesopotamian composition (Fig. 32). TBK\_048 is a small jar with a band of cross-hatch incision on the shoulder, while TBK\_068 is a small bottle (Fig. 33).

**Nineveh.** As noted above, several samples are clear outliers, indicating that they are probably non-local. Of these, four jars (NIN\_002, -005, -007, and -019) have a significant probability of group membership in our Mesopotamian reference group, when distances are assessed across the full suite of 27 elements (Figs. 34 and 35). In addition, one sample (NIN\_013) shows a strong affinity to Tell Brak, whether measured across 8 or the full suite of 27 elements, while two others (NIN\_015 and NIN\_016) join with Tell Brak on the reduced set of 8 discriminating variables (Figs. 36 and 37). Note that the samples joining with Tell Brak are not obvious outliers, and may reflect the high geochemical similarity between the two regions.

**Godin Tepe.** Of the three composition groups defined for Godin, the two smaller groups (Godin-2 and Godin-3) may be of non-local origin; however, these do not match with any of the existing reference groups defined for the region. In addition, there were four apparent outliers (GOT\_001, -003, -006, and -077). Of these, GOT\_006 has a significant probability of membership in the well-defined Tell Brak reference group; GOT\_077 is a possible member of the Abu Fanduweh group based on multivariate distance calculations, although a comparison of profiles indicates that the match is not close (Fig. 38). No probable matches were found for GOT\_001 and GOT\_003.

**Tal-e Geser.** There are a number of clear outliers within the Tal-e Geser assemblage. Three have a strong, significant probability of group membership in the Mesopotamian reference group when assessed across 27 elements (Fig. 39). These are: TG-13 (Protoliterate cup), TG-27 (Elamite), and TG-73 (Prehistoric/5th millennium BC) (Fig. 39A). One other sample, TG-55 is consistently assigned

to the Mesopotamian group by discriminant analysis, and may be a fringe member of that group. Two other outliers, TG-39 (Late Uruk) and TG-48 (Proto-Elamite), are consistently assigned to the N. Susiana group by discriminant analysis; although they are not statistical members of that group, their compositions closely parallel that of the Susiana group (Fig. 39B). One other sample (TG-30, a ring-scraper of uncertain date), not an apparent outlier, shows a significant probability of group membership in the Susiana group, and its composition is quite close to that of the mean Susiana profile, as well. It has a very distinctive paste, with linear (lath-like) mineral inclusions (Fig. 40). Our last outlier (TG-19, a small Proto-literate bowl) has no apparent matches. Finally, there is the significant (and frustrating) overlap of the Tal-e Geser Main group with Abu Fanduweh, as noted above, which may involve some movement of vessels between these regions.

**Tepe Yahya.** In spite of the stylistic similarities between Yahya and Susiana, there is no indication of ceramic trade between the two regions - a not surprising finding given the distances involved. However, Yahya seems to have been quite a busy place in terms of ceramic production, with multiple contemporary traditions or paste recipes in use. In terms of outside contacts, two chaff-tempered outliers (YAH\_003 and YAH\_024) and six grit-tempered outliers (YAH\_005, -075, -079, 090, -111, and -120) were identified. In cluster and discriminant analyses, most of these group with Tepe Yahya samples, suggesting they are just extreme members of local composition groups, while one sample (YAH\_055) is a global outlier in Ti, Hf, and Ta, suggestive of heavy metal contamination. The final sample, however, may indicate long-distance connections. YAH\_111 is consistently assigned to Godin Tepe by cluster analysis and discriminant analysis, and although it does not have a significant probability of group membership, the profiles are strikingly similar (Fig. 41). An origin at Godin seems unlikely, but perhaps contact with a geologically similar region is represented.

## SUMMARY

Our analyses indicate that ceramics from S. Mesopotamia, the Syro-Tigridian highlands, the Susiana Plain, the Ram Hormuz Plain, and sites within the Iranian plateau can be readily distinguished by their trace-element compositions, and reference groups for both grit- and fiber-tempered ceramics have been established for these key areas of political development. The exception to this regional variation involves ceramic vessels from sites along the Euphrates River - extending from Jebel Aruda on the Upper Euphrates downstream to the S. Mesopotamian alluvium - which are strongly similar in composition and differ only slightly in composition.

In general, the diversity of composition groups encountered within the corpus of Uruk-style ceramics strongly negates a substantial trade in Uruk ceramics originating in Mesopotamia. Rather, the Uruk-style ceramics found at colonies of Jebel Aruda and Tell Brak and at the trading depot at Tepe Godin, are of local manufacture, in spite of the strong similarities in form and visual paste characteristics, suggesting that potters were among those who helped found these intrusive settlements. At the same time, this study encountered a limited amount of east-west exchange among highland sites, documenting the early beginnings of trade routes favored in later historical times.

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