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Technological Changes in Pottery Production during the Third Millennium BCE: A Case Study of Tol-e Qaleh in the Kur Basin, Fars, Iran

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Abstract

The third millennium BCE in the Kur River basin of Fars is marked by the two cultures of Banesh and Kaftari. Scholars have assumed a gap in the chronological sequence between these two periods, suggesting that sedentary communities became largely dispersed during this time span. Tol-e Qaleh, a settlement site from the third millennium BCE in the eastern Kur basin, was surveyed and excavated in 2021 and 2022. The earliest and latest contexts identified by the stratigraphic excavations represent the Banesh and the Shogha-Timuran, respectively. Through laboratory examinations of a distinct pottery type, namely the red ware dating to the Banesh, a transitional phase, and Kaftari period, the present study aimed at exploring the technological transformations in the pottery of the third millennium BCE at Tol-e Qaleh: Was there continuity in the industry, or is a discontinuity evident? To this end, eight pottery samples were subjected to X-ray fluorescence (XRF) and X-ray diffraction (XRD) tests as well as petrography. The previously established presence of "anorthite phase" in the local soil attested to the local provenance of the assemblages dating to the Banesh, transitional, and Kaftari periods at Tol-e Qaleh. Moreover, the results of chemical analyses suggested that the constituent elements of the potsherds remained consistent throughout the third millennium BCE at the site.

Keywords: Pottery Technology, Kur Basin, Tol-e Qaleh, Third Millennium BCE, Red Pottery, Banesh and Kaftari Periods.

Article Type: Research Article

Introduction

Since the 1960–1970s, when the scientific study of archaeological materials came to the fore, various analytical methods have been adopted to examine the chemical composition of ceramic artefacts. In particular, elemental analysis has played a central role in identifying the provenance, production technique, and classification of artefacts in the fields of archaeology, archaeometry, geoarchaeology, and conservation of cultural material. As of its first appearance in the 1960s, X-ray fluorescence (XRF) has remained the most widely used method for quantitative and qualitative analysis of minerals in cultural artefacts. (Eslami 2015: 88). Recent studies have effectively highlighted the potential of chemical analysis of archaeological pottery as a foremost category of cultural materials in extracting socio-cultural information on ancient societies (e.g., see Arnold 1999; Hughes 1981; Noll and Heimann 2016; Rice 2015; Shepard 1957).

Scientific methods such as chemical analysis and petrography enable archaeologists to delve deeper into a pottery assemblage, including its composition, production methods, and possible sources of raw materials. These techniques can help answer important questions about the production, trade, and use of pottery in ancient societies. From archaeological point of view, the study of pottery is essential for understanding the complexities of ancient societies and provides unique insights into the lives of ancient societies.

Based on archaeological data, a significant drop in settlement occurred at Tal-e Malyan in the wake of its cultural boom during the Middle Banesh peri-

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od in the late fourth and early third millennium BCE, and there is also little evidence from the Late Banesh period in the Kur River basin (Sumner 2003: 53). A gap has been reported in the chronological sequence between the Banesh and Kaftari periods. Surface surveys, soundings, and radiocarbon age determinations show that the Kur basin experienced a major decline in population in the mid-third millennium BCE (Sumner 1988: 315-317). Sumner placed a gap between the Late Banesh (2800–2600 BCE) and the Early Kaftari period (2200 BCE). From this tentative hiatus, he concluded that sedentary inhabitants were greatly dispersed during the latter period, leaving large parts of the Fars region to nomadic groups (Sumner 2003: 13-117; 2003, 54-55).

The recently published evidence from Trench H5 and the new excavations of Trench H1s at Tal-e Malyan excavated by W. Sumner have now furnished unequivocal indications of settlements intervening in the two concerned periods, indicating that at the time the Kur basin was occupied by sedentary communities (Miller and Sumner 2004; Alden *et al*. 2005). These two soundings have disclosed a distinct stylistic transition from Banesh to Kaftari above the levels characterised by assemblages typical to the Banesh period (Miller and Sumner 2004). Excavation at Toll-e Gap Kenareh near Persepolis produced Banesh pottery assemblages in Trenches A and B (Khanipour 2012). Here, in the deposits overlying the latest Banesh levels, at a depth of 4 m, the Banesh pottery constitutes only a rather small percentage of the assemblages that are predominated by the Kaftari material, and even towards the upper levels the former is steadily diminished in favour of the latter (Khanipur 2012: 210). The recent publication on Tell Malyan (Miller and Sumner 2004) and the evidence from Toll-e Gap Kenareh speak of the possible evolution of the Kaftari tradition out of the earlier tradition that was popular in the Fars region in the Banesh period and the mid-third millennium BCE (Khanipour 2012: 214).

At Tol-e Kamin, 168 pottery pieces (spanning from the Chalcolithic to the Neo-Elamite period) were chemically analysed with a portable XRF device to determine the provenance of the concurrent assemblages. The results showed substantial shifts in clay resources from the Proto-Elamite to the Neo-Elamite period (Eslami *et al.* 2020). This study, however, only considered stylistic continuation observed at one or two sites by XRF analysis of pottery collections found from the surface of the sites. Thus, no coeval pottery deriving from a stratigraphically controlled excavation has yet been chemically examined in terms of technological aspects such as firing degrees or constituent elements. Investigations at Tol-e Qaleh of Marvdasht revealed third millennium BCE (Banesh and Kaftari) pottery during the survey and the recent stratigraphic trench 2. To grasp the mineralogical characteristics of the related assemblages, samples from the Late Banesh period, the transition phase, and the Kaftari period were subjected to chemical analyses. The fieldwork at Tol-e Qaleh has thus set the stage for a better understanding of this period.

History of Research

Initial Excavations and Cultural Identification

In 1952 and 1955, L. Vanden Berghe conducted two seasons of excavations at Tol-e Qaleh as part of a larger field project focussed on establishing cultural and chronological sequences for the prehistory of Fars Province. These excavations, along with surface collection of sherds, marked significant steps towards dating the region and understanding its pottery traditions. Vanden Berghe identified distinct ware types associated with various cultures, naming them after key sites where each type was first found. Tol-e Qaleh was recognised as representing "Qaleh Ware" (second millennium BCE) (Haerinck and Overlaet 2003: 193).

First Chemical Analysis of Pottery

In 1981, J. Blackman carried out the first chemical analysis of pottery from the Kur Basin in Fars Province. He analysed 50 straw-tempered, 54 sand-tempered, and 15 mixed sand-and-straw-tempered potsherd from trenches TUV and ABC at Tal-e Malyan. Blackman's laboratory analysis, which included optical microscopy and X-ray diffraction, provided insights into pottery technology, specialisation, and the organisation of regional interactions during the early urbanization of the Iranian highlands. His study was focussed on chemical variations in locally produced pottery and explored the use of elemental concentrations in local clays for diagnostic purposes, establishing a link between clay and pottery types (Blackman 1981).

Recent Chemical Analyses

In 2020, a joint expedition from Goethe University and the Iranian Centre for Archaeological Research (ICAR) conducted chemical analyses of 168 pieces of pottery from Chalcolithic to Neo-Elamite periods from Tol-e Kamin in the Kur Basin using portable

XRF. The findings showed significant changes in clay sources from the Proto-Elamite to the Neo-Elamite periods (Eslami *et al*. 2020). In a 2022 study, 21 potsherds from the Neolithic to Bronze Age were analyzed from 13 different sites across the basin using Raman spectroscopy to identify the pigments used for the red and black painted decorations. The study showed that manganese and haematite were the primary materials used for the red and black paints, with carbon black used for Bakun-period pottery (Vermeersch and Rousaki 2022: 1402).

Petrographic and Microscopic Studies

To investigate raw material structures techniques of firing from the 8th to 3rd millennium BCE, pottery samples from 10 sites in the Kur Basin—including Tol-e Shagha, Tol-e Timuran, Tol-e Kamin, Tol-e Darvaza, Tol-e Qaleh, and Tal-e Malyan—were analysed using cathodoluminescence microscopy (Emami *et al*. 2021). These analyses, supplemented by petrography and SEM, helped identify the raw materials and inclusions used, providing insights into production techniques, exchange systems, and decoration types. This comprehensive analysis focused on understanding the provenance and technological processes of pottery from the mid-to-late second millennium BCE.

New Research Using Portable XRF

In a more recent study, Pincé and colleagues re-visited the assemblages collected by Vanden Berghe in the 1950s using handheld X-ray fluorescence spectrometry. The goal was to obtain elemental data for studying raw materials, production techniques, and exchange systems. A sample of 26 pieces from the Neolithic to the Bronze Age was analysed and classified into five compositional groups. This study demonstrated how chemical correlations among pottery corpora could be used to reconstruct production processes and provenance. The sites examined included Tol-e Shogha, Tepe Timuran, Tol-e Kamin, Tol-e Darvaza, Tol-e Qaleh, and Tal-e Malyan (Pincé *et al.* 2016).

Materials and Methods

for collecting third millennium BCE pottery samples from the Kur basin, Tol-e Qaleh was chosen for a case study. A systematic survey covered the site in the first season, which would be followed by an excavation in the second.

Location of Tol-e Qaleh

The archaeological site of Tol-e Qaleh lies in the Marvdasht plain at N29972237, E52968736, at an altitude of 1607 m above sea level. The site is 5 km east of Istakhr, close to the Hasanabad Sanjarlu village of Sidan District in Marvdasht County of Fars Province. Tol-e Qaleh consists of five smaller hills interspersed among farmlands (Figure. 1). In his survey, Vanden Berghe designated these as Hills 1 to 5, from north to south or from larger to smaller (Haerinck and Overlaet 2003).

Today, the site covers an area of about 5 hectares, rises 9.5 metre above the surrounding land, and is located 70 metre from the Sivand (Poulvar) River (Figure. 2). The river represents the principal environmental feature and water resource near Tol-e Qaleh. It is noteworthy that the geomorphological survey of a part of the Poulvar basin has revealed a series of alluvial layers (Rigot 2010: 57). The most notable of these, a 17-m-thick formation, was mainly composed of silt during the early and middle Holocene.

Systematic Survey of Tol-e Qaleh

The systematic survey at Tol-e Qaleh was primarily designed to accurately register the physical and structural aspects of the site and the distribution and density of surface cultural materials from different periods, especially the third

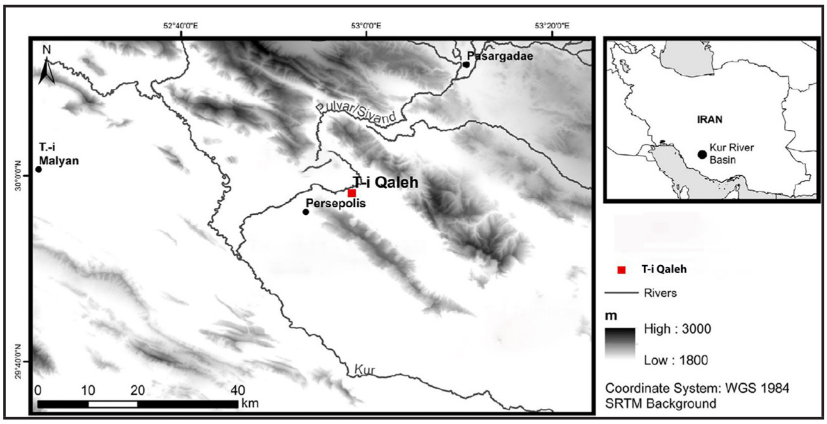

Figure. 1: *The location of Tol-e Qaleh (After:Pincé et al. 2016: 151)*

Figure. 2: *Aerial view of Tol-e Qaleh in Marvdasht (Photo by Ali Aghrah)*

millennium BCE, and also to propose an excavation programme for the site. Thus, geographical data (satellite and aerial images) and geographical information systems (GIS) were used to document the site and investigate its geographical extent to evaluate the processes of site formation, erosion, and disturbances. A multi-frequency GPS device was used to set up a grid system to facilitate systematic survey and sampling. The surface finds were later integrated into a database to carry out statistical analyses. In pursuit of the stipulated objective for the project's first stage, attempts were made to collect as much information as possible about the site's current state by adopting the most fitting and precise methodology. Therefore, drone photogrammetry was applied given its high accuracy and speed, high-quality maps, capability for volume calculation, and diversity of outputs such as orthophotos with high spatial resolution and accurate 3D models.

The first phase of the project prepared a map of Tol-e Qaleh and its 160-hectare area, including the hills around the site, the farmlands encircling it, and the bank of the Sivand River, with a Phantom 4 Pro V2.0 drone based on a large number of aerial images. In preparing the map, before the actual flight, control points were established on the site's surface, and their precise coordinates were registered by the GPS. Then, the initial measures for the flight were planned, and the executive instructions for adjusting the camera and adapting it to the environmental conditions were loaded on the flight controller. The drawn topographical maps show the site today covers a total area of 5.5 hectares, consisting of 5 smaller hills formed 50 m south of the Sivand River, and rising 9 m from the surrounding lands.

Once the mapping was completed, a grid system covered the entire area of the site. The team attempted to collect the necessary data to answer the major questions of the project through a systematic, intensive survey and collecting surface materials in a controlled manner within the plotted grids. Thus, a 20-m interval grid system was imposed in a north-south direction. The grid units along the vertical and horizontal axes were marked by Latin letters and sequential numbers, respectively. A total of 210 squares, marked with rope, produced 2,190 small finds. Analysis of the pottery collections at the end of the survey indicated that the site dates back 8000 years. The represented periods include the Neolithic (Mushki, Bashi), the Chalcolithic, the Proto-Elamite (Bakun, Lapui, Banesh), the Elamite (Kaftari, Qaleh, Shogha-Timuran), the Iron II and III, the (Achaemenid), the Sassanian, and the Islamic.

Stratigraphic Excavation at Tol-e Qaleh

Given the predefined objectives and the findings made during the survey, Mound 2 in the southern quadrant of the site was selected for excavation. A 3× 3 m stratigraphic trench, Trench 1, was then opened on top of the mound, where 3 contexts would be exposed. The excavation had to stop at a depth of 35 cm, where a profusion of bricks covered the entire surface of the trench as a consistent layer.

It is notable that the pottery assemblage from this trench is characterized by the typical brick-red Achaemenid material (Figure. 3).

As the brick floor level, related to Achaemenid architecture, hampered the work in Trench 1, Trench 2 was excavated on the southern mound to clarify the sequence of the occupational layers at Tol-e Qaleh. Measuring 2 ×3 m, this south-north-orientated trench lay 15 m from Trench 1 on the sloping (more southern) part of the mound (Figure. 4). The 6.10 m deep deposit excavated in this trench yielded 39 contexts in total, encompassing a sequence of occupation phases spanning the Banesh, Kaftari, Qala, and the Shogha-Timuran periods (Table. 1). In Context 2034, a large jar 90 cm high was discovered at the centre of the trench. This third-millennium BCE receptacle finds parallels among the large jars from the site of Jelian in Fasa (Figure. 4). Context 2037, in the eastern corner of the trench, produced a burial jar containing a human skeleton in a squatting position, which, in light of its pottery type, is datable to the Late Banesh period.

Laboratory Studies

Three specimens were subjected to an XRD test at the laboratory of the Tehran-based Razi Metallurgical Research Centre (Figure. 5). X'Pert Highscore Plus software identified the existing phases and the applied firing temperatures. Invoked to obtain a more complete picture of the samples, the results of the semi-quantitative XRF analyses are reported in Table 1. LOI was measured at 950 °C with an ignition period of 1.5 hours.

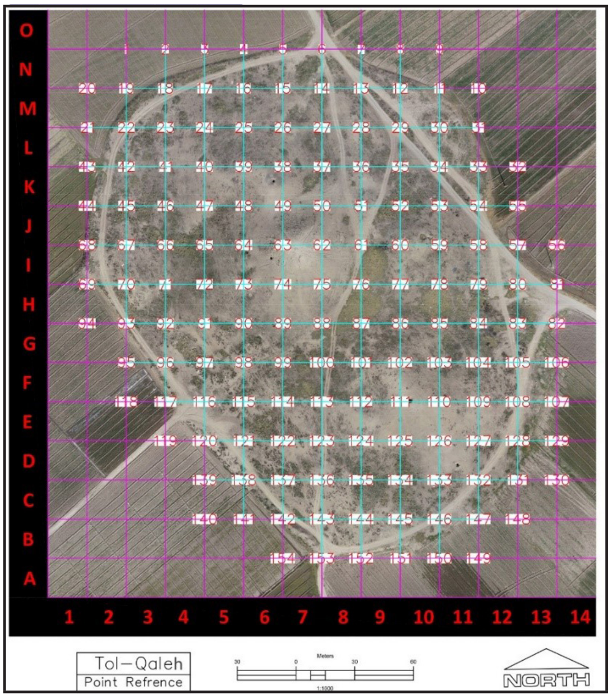

Figure. 3: Grid system staked out over Tol-e Qaleh for horizontal control during the systematic survey (Photo by Ali Aghrah).

As regards ceramic petrology and thin-section study, five samples of the Banesh and Kaftari periods from Tol-e Qaleh were sent for analysis to the laboratory of the Research Centre for Conservation of Cultural Relics in Tehran, where the prepared thin sections were examined with a James Swift binocular polarising microscope at a magnification of 4 x (Figure. 6).

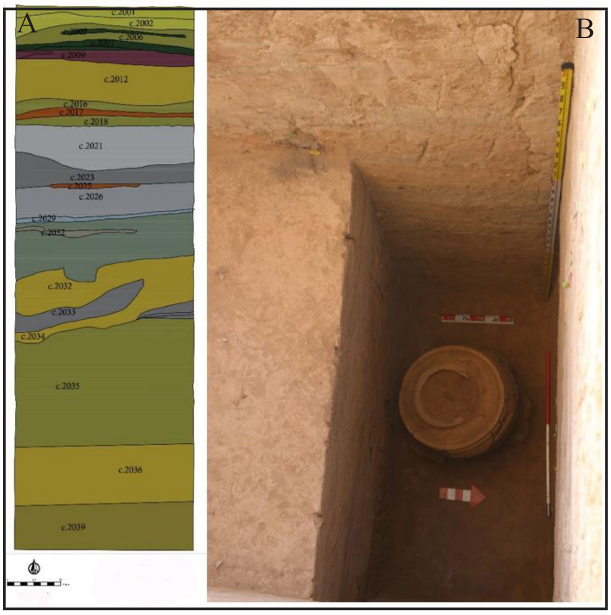

Figure. 4: *A: The plan of the layers in the western wall of Trench 2. B: A view of Trench 2 after excavation,*

Results

X-Ray Diffraction Test (XRD)

The analysis of the XRD test covered three samples: a plain (undecorated) redware from Context 2038 with a relative date of the Banesh period, and a plain and a painted sample, both in redware deriving from Context 2034 of Trench 2 dating from the third millennium BCE (the period of purported hiatus between the Banesh and Kaftari horizons). The results are given schematically in Figure 7.

The XRD analyses showed the presence of the characteristic quartz phase as the main constituent in all three samples. With the reference code JCPDS no. 00-005-0490, the phase has a hexagonal crystal structure and space group of p3121. The mineral was added as the main temper or filler (Figure. 7).

Other attested phases in all three specimens include calcium aluminosilicate. Two phases of anorthite ($CaAl_2Si_2O_8$) and gehlenite ($Ca_2Al_2SiO_7$) with reference codes JCPDS nos. 00-009-0216

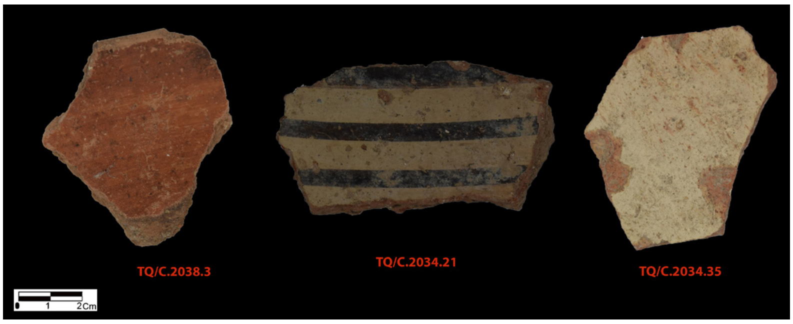

Figure. 5: *Samples examined with XRD and XRF.*

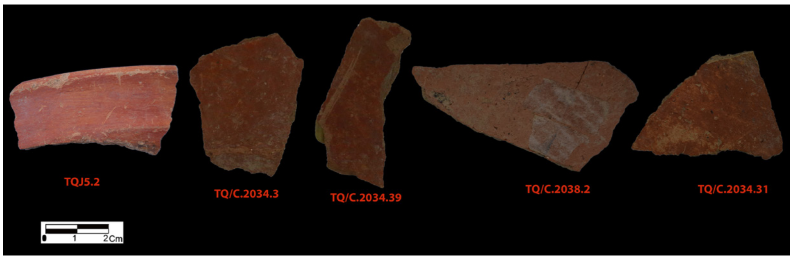

Figure. 6: *Samples examined through petrography.*

Table.1: *Contexts recorded in Tol-e Qaleh Trench 2*

Context no.	Relative Date	Description	Context no.	Relative Date	Description	Context no.	Relative Date	Description
2001	Shogha-Timuran	Turf	2014	Kaftari	Pit	2027	Transitional	Ash
2002	Shogha-Timuran	Debris	2015	Kaftari	Cut	2028	Transitional	Debris
2033	Shogha-Timuran	Bricky debris	2016	Kaftari	Debris	2029	Transitional	Brick vent pipe
2004	Shogha-Timuran	Ash	2017	Kaftari	Beaten floor	2030	Transitional	Vent pipe cut
2005	Shogha-Timuran	Ashy loose soil	2018	Kaftari	Ash	2031	Transitional	Dense soil
2006	Shogha-Timuran	Ash	2019	Kaftari	Beaten floor	2032	Transitional	Beaten floor
2007	Shogha-Timuran	Green soil	2020	Kaftari	Debris	2033	Transitional	Debris
2008	Shogha-Timuran	Loose, fine soil with ash	2021	Transitional	Bricky debris	2034	Transitional	Beaten floor
2009	Shogha	Beaten floor	2022	Kaftari	Lime mortar	2035	Transitional	Soil debris
2010	Qaleh	Fine soil	2023	Transitional	Soil	2036	Banesh	Burial jar
2011	Qaleh	Pit	2024	Transitional	Oven vent pipe	2037	Late Banesh	Burial jar
2012	Qaleh	Beaten floor	2025	Transitional	Beaten floor	2038	Late Banesh	Soil
2013	Kaftari	Red, heated soil	2026	Transitional	Soil debris	2039	-	Virgin soil

and 00-041-1486 were detected in tetragonal (quadrilateral crystal structure) (space group P-421m) and triclinic (space group P-21) crystal systems, respectively. This group of minerals is otherwise known as mica. XRD also revealed the presence of iron oxide (hematite) with the chemical formula Fe_2O_3 and reference code JCPDS no. 0534-013-00 (with a rhombohedral lattice and space group R-3c) in all samples. In this crystal structure, all lattice parameters, i.e., faces and angles, are equal but are not 90° and are below 120°. Occurring only in the simple form, this structure is found in such minerals as dolomite and hematite. The grossite phase ($CaAl_4O_7$; JCPDS no. 00-046-1475) occurred only in Sample 2 (TQ/C.2034.35), crystallised in a monoclinic lattice with space group C2-c.

In Samples 1 and 2, the calcite phase with reference code JCPDS no. 005-005-005 and rhombohedral lattice and space group R-3c was present. While Sample 3 (TQ/C.2038.3) contained a significant diopside phase (Ca (Mg,Fe,Al)(Si,Al)$_2$O$_6$) with reference code JCPDS no. 00-038-0466 and a monoclinic crystal system and space group C-2c.

LOI is lower in the former, attesting to its exposure to a higher kiln temperature than Sample 2. However, the presence of significant calcite phases in both samples (based on XRD measures) suggest kiln temperatures below 800 °C. The very similar values of TiO_2, and Fe_2O_3 in Samples 1 and 3 may indicate a single/related raw material source(s), while Sample 2 exhibits slightly varying contents of the compounds.

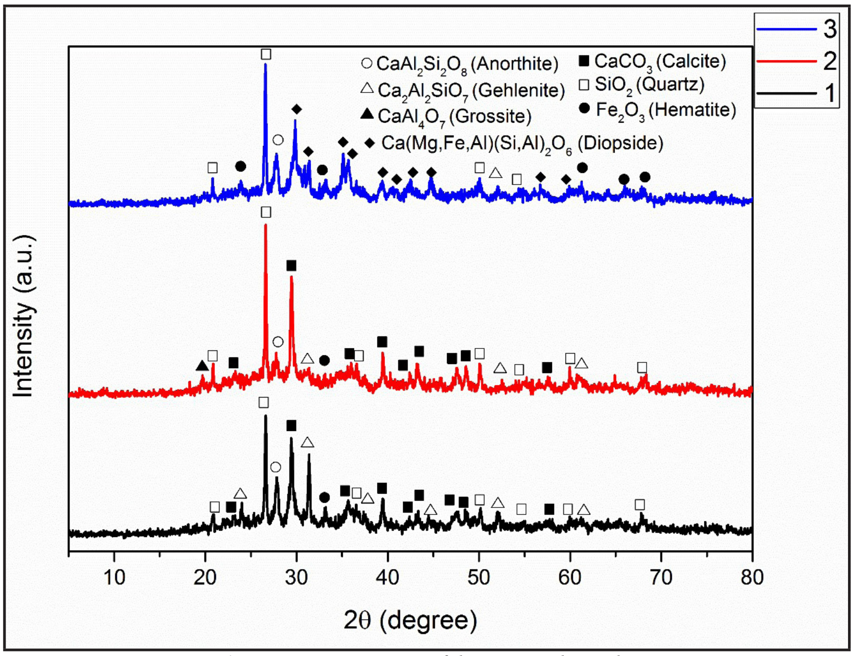

Figure. 7: *XRD patterns of the examined samples.*

(After: Razi Metallurgical Research Center Laboratory)

XRF

The results of the XRF analyses on the three samples are outlined in Table 2.

According to Table 2, the LOI value for Sample 3 is significantly lower than those for the other samples, possibly due to the higher firing temperature of the original vessel (above 800 °C), which caused thermolabile compounds (such as calcite phase) escaped the matrix. This observation is in agreement with the XRD finding of a higher kiln temperature for the same specimen. The fewer sulphur phase in this specimen further strengthens this scenario as the substance will likewise evaporate at higher temperatures. Regarding Samples 1 and 2,

In general, the main compounds of interest for pottery classification can be classified based on Noll's ternary graph of (CaO+MgO) –Al_2O_3–SiO_2, where the Al_2O_3–SiO_2 axis represents the clay's chemical composition, while the SiO_2–CaO+MgO axis represents the percentage of additives and transition pyroxene compounds that form at high temperatures (Noll and Heimann 2016).

As clearly shown in Figure 8, the three considered samples all fall in almost the same area of the triangle, indicating their homogeneity and the exploitation of similar raw materials. In geological terms, there is a genetic relationship between the samples. These samples fall in the lime-rich fabric

Table. 2: *The weight percentage of oxide compounds in the examined samples, as determined by the XRF test*

Sample	Code	SiO_2	Al_2O_3	MgO	Na2O	TiO_2	CaO	K2O	SO_3	Fe_2O_3	P_2O_5	LOI
1	TQ/C.2034.21	34.37	14.3	2.0	0.34	1.2	21.1	2.6	0.15	14.2	0.11	9.53
2	TQ/C.2034.35	42.28	12.5	3.4	0.7	0.94	15.7	1.3	0.14	10.7	0.17	12.17
2	TQ/C.2038.3	42.4	14.7	4.3	0.57	1.1	17.39	1.3	0.09	14.9	0.15	3.1

class that has already been reported for the pottery from Rahmatabad as well. As stated earlier, the closely related compositions of Samples 1 and 3 slightly vary from that of Sample 2.

Figure 9. clearly shows that the attested compounds in all three samples have transformed within almost the same range relative to SiO_2, a fact suggesting that the original vessels shared the same origin, derived from a single geological formation, and went through a similar geological process.

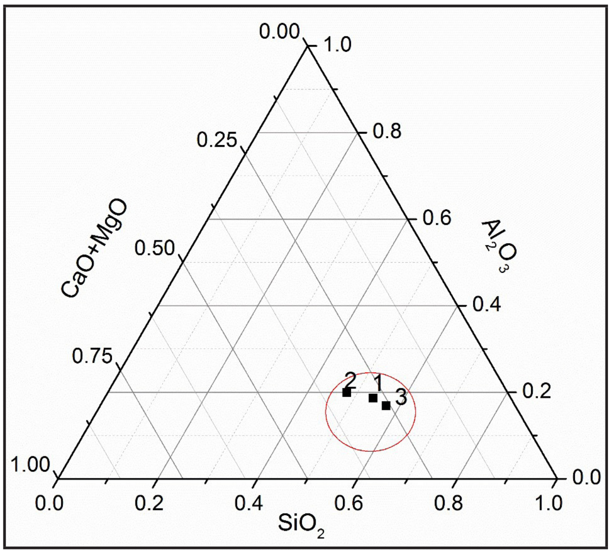

Figure. 8: *Noll's ternary graph used for classification of the examined pottery samples*

(After: Razi Metallurgical Research Center Laboratory)

Petrography

Microscopic study of the four samples, namely T.Q.C.2034–39, T.Q.C.2034–32, T.Q.J.5–2, and T.Q.C.2038–31, revealed that they consist of grog, calcite, quartz, and iron as major elements , which combine to form a matrix with a heterogeneous (porphyry) texture (Figures. 10-13).

The examined samples all shared a similar microscopic structure. Grog inclusions were added as a filler (temper), and they consisted of red clay crumbs, crushed pottery, and red silt lumps. These inclusions make up about 20% of the total volume of the fabric and vary in size (<1 cm). The calcite phase, although not abundant, accounts for only about 5% of the volume of the fabric, where it tends to occur as relatively large particles. The presence of this thermal indicator phase suggests firing temperatures below 800°C for the ceramic bodies in question. Quartz was detected as a fine-grained, single crystal with a very limited phase. The four samples consistently showed a fabric of

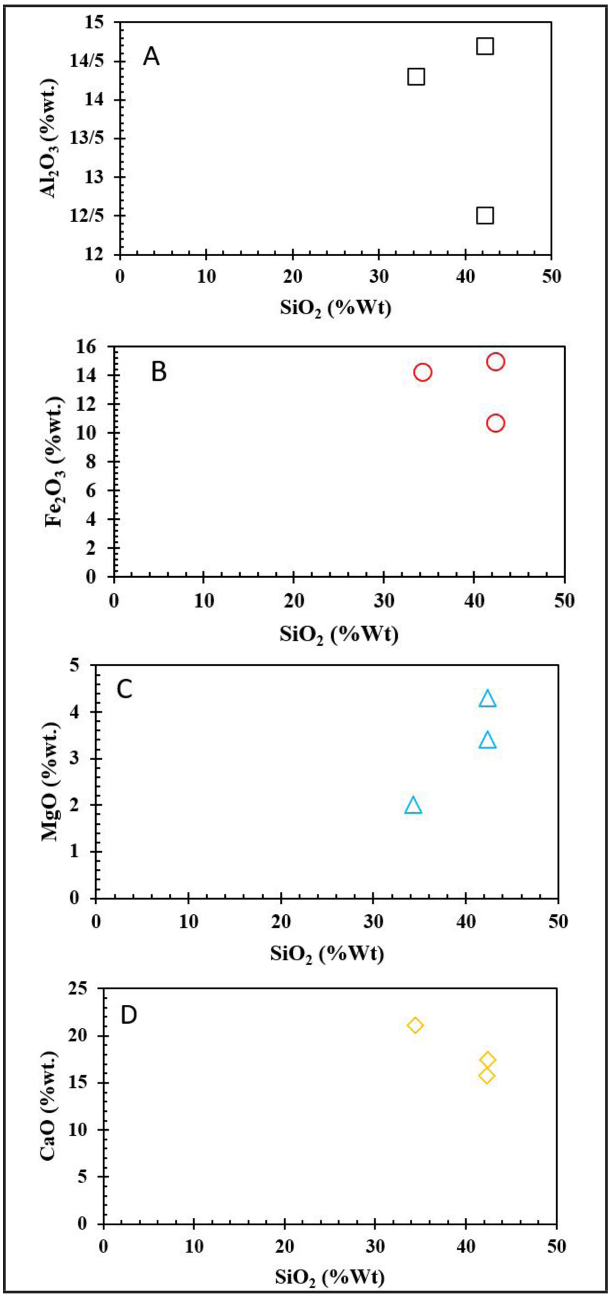

Figure. 9: *Graphs showing the differences of SiO_2 relative to (A) Al_2O_3, (B) Fe_2O_3, (C) MgO, and (D) CaO (by weight percentage) for provenance investigation of the raw materials samples*

(After: Razi Metallurgical Research Center Laboratory).

non-carbonate composition in red colour. The firing process had, to some extent, altered the fabric. The latter contained relatively abundant voids seen as vesicles (spherical and oval) and occasionally channels (thin and elongated).

Microscopic study of Sample T.Q.C.2037–2 revealed a non-carbonated, bicoloured, heterogeneously textured silty fabric composed of clay crumbs (grog), calcite, quartz, and iron (Figures. 14 and15). This specimen stands out from the previous four samples by its clay fabric composition. The abundant voids also give it a porous texture. Large, light-colored clay lumps were added as filler or temper. Calcite accounted for about 5%, while quartz, in both phenocryst and polycrystal morphologies, proved to be a main component of the fabric at 10%. Iron compounds were observed in dark to red color. The colour differentiation (bicolority) of the paste resulted from firing conditions and had nothing to do with its composition. As seen in the photomicrographs, both the red and grey fractions are identical compositionally (Figures. 14-16).

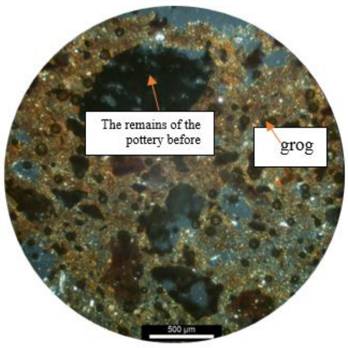

Figure. 10: *Photomicrograph of Sample T.Q.C.2034-39. Heterogeneous texture with grog inclusions (pottery fragments) added as filler. XPL. Image width = 2.7 mm (After: Petrography Laboratory of Conservation and Restoration Research Institute, by Iraj Beheshti)*

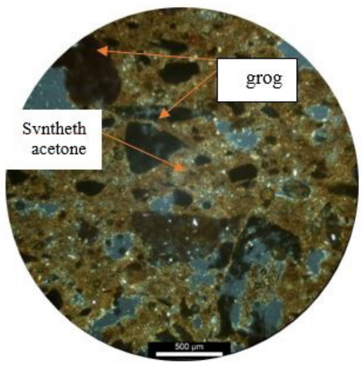

Figure. 11: *Photomicrograph of Sample T.Q.C.2034-32. Heterogeneous texture with grog particles. XPL. Image width = 2.7 mm (After:Petrography Laboratory of Conservation and Restoration Research Institute, by Iraj Beheshti)*

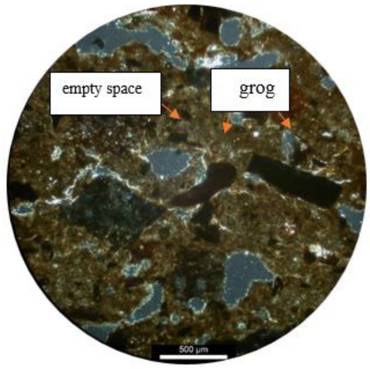

Figure. 12: *Photomicrograph of Sample T.Q.J.5-2. Heterogeneous texture with grog inclusions. Voids appear in dark colour. XPL. Image width = 2.7 mm (After: Petrography Laboratory of Conservation and Restoration Research Institute, by Iraj Beheshti)*

Figure. 13: *Photomicrograph of Sample T.Q.C.2038-31. Heterogeneous texture. Grog inclusions were intentionally added during clay mixing. XPL. Image width = 2.7 mm (After:Petrography Laboratory of Conservation and Restoration Research Institute, by Iraj Beheshti)*

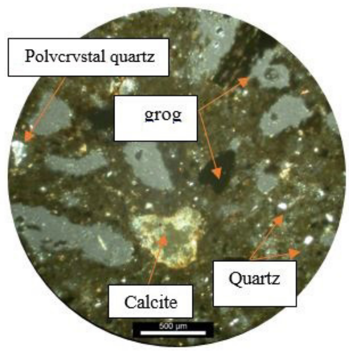

Figure. 14: *Photomicrograph of Sample T.Q.C.2037-2; Heterogeneous silty texture; Grog and calcite inclusions act as filler or temper. The light-coloured quartz particles stand out in the fabric. XPL. Image width = 2.7 mm(After:Petrography Laboratory of Conservation and Restoration Research Institute, by Iraj Beheshti)*

Discussion

Available archaeological datasets for the Kur basin suggest that permanent settlements were almost absent over most of the third millennium BCE. The deposit intervening the Banesh and Kaftari periods in Trenches ABC and BY8 at Tal-e Malyan shows signs of an elongated erosion and deposition cycle following the Banesh period. The same debris layer sealing the Banesh levels was also encountered in other trenches (GHI, F26, and Z46), but the limited extent of excavations in these areas does not allow for any definitive interpretations (Sumner 1989). Excavation at Tol-e Qaleh suggested that, based

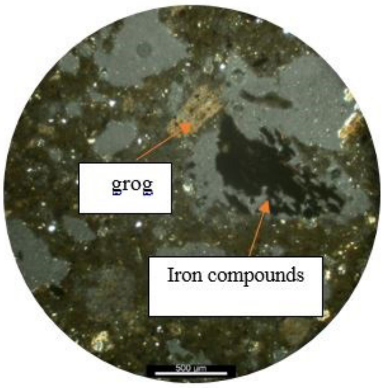

Figure. 15: *Photomicrograph of Sample T.Q.C.2037-2; Heterogeneous silty texture; Light coloured grog fragments along with dark iron compounds. XPL. Image width = 2.7 mm*
(After:Petrography Laboratory of Conservation and Restoration Research Institute, by Iraj Beheshti)

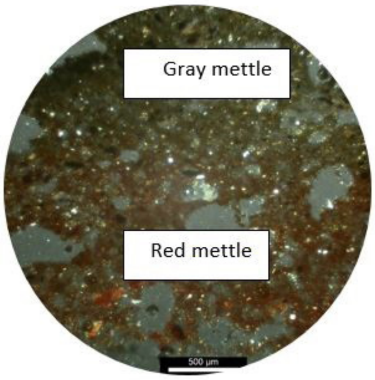

Figure. 16: *Photomicrograph of Sample T.Q.C.2037-2. The bicolor fabric shows a gray and a red fraction. Both fractions share the same composition, and the color difference relates to firing conditions of the original artefact. XPL. Image width = 2.7mm*
(After: Petrography Laboratory of Conservation and Restoration Research Institute, by Iraj Beheshti)

on comparative data, occupations existed at the site during the third millennium BCE. A detailed analysis of the exposed stratigraphy and the sampled ceramics from the site shows that the settlement persisted uninterruptedly from the Banesh to the Kaftari period. Chemical analysis of the red ware sherds dating to the Banesh, the transition, and the Kaftari periods by XRD and XRF methods and petrography indicated the presence of an anorthite phase. As Blackman (1981) has demonstrated the presence of anorthite phase in the regional soil, this observation supports the idea of local production of these pieces. Another common phase in the region's soil in Blackman's study was dolomite, the absence of which in the examined specimens may indicate that the original thermal samples were fired at a temperature higher than 700 °C.

Another significant crystalline phase in ancient pottery that serves as a thermal indicator is calcite. According to Figure 4, a significant calcite phase is present in Samples 1 and 2, while Sample 3 does not exhibit this compound, suggesting its possible exposure to a higher kiln temperature.

A significant diopside content was detected in Sample 3. As another thermal indicator, this phase suggest a firing temperature of 900-950 °C (Blackman 1981).

Hematite either forms as a secondary mineral through oxidation in warm climates or in the kiln, or represents a legacy from soil's parent materials. In regions where this mineral is not naturally present, its presence serves as a thermal indicator. The phase has been identified in the pottery assemblage at Tappeh Rahmatabad (Emami *et al.* 2022).

Eslami and colleagues (Eslami *et al*. 2020), in their work on the pottery from Tol-e Kamin in the Kur Basin, found that in the Kaftari and Banesh potteries—respectively coinciding in date with Samples 1 and 3 here—the mass percentages of iron, aluminium, and titanium were significantly higher than other pottery types. Therefore, the higher percentage by mass of iron, titanium, and aluminum-based compounds in Samples 1 and 3, compared to Sample 2, corroborates the chronological correlation between the two relevant pottery types and the types that prevailed in the Kaftari and Banesh horizons. Further, Blackman and his colleagues have described the Banesh pottery as consisting of a coarse body with a significant sand content, a trait interpreted as a local response to the new socio-economic need for large storage jars in the period (Blackman 1981). Table 2 also shows that Sample 3 (dating to the Banesh period) contains a higher amount of SiO_2 than the other two specimens, supporting Blackman's claim. In the compositional analysis of the specimens, quartz was detected in angular morphology, indicating that the mineral either had not moved far from its origin or was intentionally added by the potter.

Conclusion

The present paper analyzed the diversity of compounds found in the Tol-e Qaleh pottery from the Kur Basin during the third-millennium BCE. Chemical analyses identified phases such as anorthite and diopside in the potsherds dating to the Banesh, Transition, and Kaftari periods. These phases will indicate higher firing temperatures, particularly in the case of diopside. On the other hand, the presence of calcite and hematite phases suggests different kiln temperatures. Such observations may point to the diversity of the technologies involved in pottery production during the third millennium BCE. The analysis also revealed that pieces from the Banesh to the Kaftari periods contain higher amounts of iron, aluminium, and titanium. This suggests that the associated pottery types fall within the same chronological horizon Mineralogical characterisations suggest that the pottery industry mainly relied on local raw material resources within the basin.

Based on the laboratory studies, it is evident that the varied mineral compositions reflect different kiln atmospheres and firing techniques, underscoring the technical advancements in pottery production. The identification of diopside, which forms at temperatures above 1000°C, suggests that certain samples were fired at exceptionally high temperatures, indicating specialized kiln management practices. Furthermore, the presence of calcite in other samples points to lower firing conditions or incomplete calcination, reflecting variability in the technological skill or resource availability among different potters.

The laboratory findings also suggest that the iron-rich compositions, prevalent in the Banesh and Kaftari periods, may have influenced the distinctive coloration of the pottery, aligning with specific stylistic or functional choices. This aspect of pottery technology, as revealed through chemical analysis, provides clues to both the economic and cultural factors driving pottery production during the third millennium BCE.

All these observations can be interpreted as indicating that a general continuity characterized the local pottery technology during this period. However, the analyses reported in this paper are not sufficient to offer a complete picture of the different facets of pottery manufacturing in the region. A more accurate understanding of technological processes requires taking into account several other factors like pottery forms, their application in daily life, and pertaining social and cultural implications.

Of major questions of interest for future investigations, one may refer to the interactions between the study area and other regions. Inquiries into the impacts of cross-regional trade and cultural interactions on pottery models and technologies will immensely contribute to reconstruct the evolution and transformations of regional pottery technology. By furnishing extensive analytical data on chemical compounds, mineralogy, and geochemistry, the present paper aims to foster a new perspective towards pottery technology in the third millennium BCE as well as a more refined picture of the coeval economic and cultural developments in the Kur basin.

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