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## Petrographic and XRF Analysis of Jemdet Nasr Pottery from the Mehran Plain, Southwestern Iran

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### Abstract

Southwestern Iran occupies a pivotal position in Iranian archaeological research, particularly concerning the proto-urban and early historic eras. Within this context, the Mehran Plain of Ilam Province is distinguished by cultural remains that are contemporaneous with and analogous to Jemdet-Nasr assemblages. Settlement data indicates that during this era, the Mehran Plain was intrinsically linked to, and shaped by, the environmental and cultural trajectories of Mesopotamia. To elucidate the proto-urban period -a phase defined by profound socio-political and economic complexity-and addressing the limited understanding of this epoch in southwestern Iran, fourteen Jemdet-Nasr pottery sherds from Mehran Plain sites were selected for laboratory analysis, having been procured through excavations and systematic surveys. The study aimed to ascertain whether the Jemdet-Nasr ceramics of the Mehran Plain were manufactured locally or were the products of Mesopotamian specialists imported into the region. Archaeological data from Choghā Ahowān and Choghā Boicheg provides robust evidence for indigenous ceramic production within the plain. Petrographic analysis demonstrated the ubiquitous presence of calcite in all samples, manifesting as both micrite and sparite. These findings are corroborated by XRF results; in certain specimens, calcite exhibits thermal alteration with only reaction halos persisting, whereas in others, its preservation implies firing temperatures did not exceed 800°C. Synthesizing geological surveys of the Mehran Plain with laboratory data, it is deduced that the majority of the pottery was fabricated locally. Consequently, while stylistic attributes, forms, and manufacturing techniques display affinities with Mesopotamian counterparts, these similarities are indicative of cultural interaction rather than direct importation, though validating this hypothesis necessitates further inquiry into production facilities and in situ ceramic assemblages.

**Keywords:** Jemdet-Nasr Period, Mehran Plain, Petrography, XRF, Southwestern, Iran.

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## Introduction

Southwestern Iran occupies a central position in archaeological research, particularly regarding the emergence of early urban societies. Despite nearly 150 years of archaeological investigations in this region, the Jemdet Nasr period remains poorly understood, largely because most excavations related to this period have been conducted in Mesopotamia, often within temple complexes.

Chronologically encompassing the late fourth and early third millennia BCE (ca. 3200–2900 BCE), this era aligns in southwestern Iran with the Proto-Elamite cultural tradition; in western Iran and Mesopotamia with the Jemdet Nasr cultural horizon; and across the Zagros highlands and segments of the Iranian Plateau with the Kura–Araxes (Transcaucasian) tradition. Throughout this epoch, the historical foundation of cities was established, paralleled by the emergence of characteristics intrinsic to early urbanism, including craft specialization, administrative structures, and the advent of early writing and record-keeping systems.

The inception of the Proto-Elamite period is dated to approximately 3200–3100 BCE, with diagnostic artifacts comprising bevel-rim bowls (BRB), clay tablets inscribed with Proto-Elamite script, and cylinder seals. This chronological phase is contemporaneous with the Late Uruk and Early Dynastic I–II horizons in Mesopotamia and the western peripheries of the Susiana Plain. The Mehran Plain in Ilam Province has yielded cultural assemblages analogous to Jemdet Nasr materials. Settlement patterns indicate that during this era, the region was intrinsically connected to Mesopotamian environmental and socio-economic trajectories. Prior scholarly research has largely concentrated on the typological classification of Jemdet Nasr pottery within the Mehran Plain; however, while evidence from Choghā Ahowān and Choghā Boicheg implies indigenous production, systematic mineralogical or chemical provenance investigations have hitherto been absent. Consequently, this research seeks to establish the provenance of these ceramics and estimate their firing temperatures via petrographic thin-section analysis and X-ray fluorescence (XRF). Thin sections were examined utilizing a James Swift polarizing microscope (4× magnification) at the Conservation and Restoration Research Institute in Tehran, while XRF analyses were performed employing a SPECTRO XEPOS spectrometer (AMETEK), with data processing conducted through XLab Pro software.

## The Ceramic Assemblage

Overall, the ceramic remains from the Early Urban period of Mehran exhibit a comprehensive affinity with documented Mesopotamian assemblages. This collection can be categorized into two primary groups: Coarse and Fine wares.

### Coarse Wares

The coarse vessels are characterized by light brown or buff hues, featuring vegetal tempering. They are handmade and devoid of any surface decoration. These ceramics primarily appear as handleless jars with irregular surfaces. The recovery of numerous ceramic scrapers from excavations at Chogha Ahowan, as well as surface surveys of other sites, provides direct empirical evidence of the manufacturing process for this ware.

Morphologically, this assemblage is categorized into two primary typological groups:

**1. Jars:** Characterized as spritless (lacking spouts), these vessels possess an average depth of approximately 50 cm. They display a firing spectrum ranging from medium -evidenced by a light grey core- to well-fired. The dominant chromatic variation extends from light reddish buff to brown.

**2. Bowls:** These vessels share a comparable fabric and color signature and are interpreted as a technological continuation of the Uruk BRB tradition. The forms were recovered in miniature, small, and medium dimensions, incorporating both flat and ring bases.

### Fine Wares

The fine ceramics generally replicate the morphological forms of the coarse group yet are distinguished by a well-levigated fabric and mineral tempers. These vessels are embellished with monochromatic, bichromatic, and polychromatic geometric motifs. This ware is observed exclusively within a buff color spectrum, manifesting most frequently as small basket-handled or spouted jars, alongside medium-to-large storage jars.

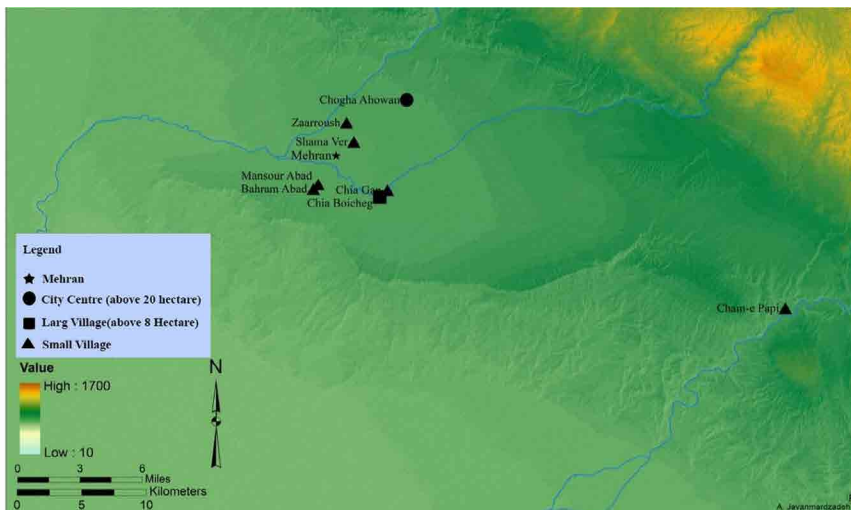
- **Decorative Variation:** In the smaller jars, monochromatic motifs -predominantly ranging from light to dark black- are applied with relatively limited technical proficiency. Conversely, the larger jars demonstrate a heightened degree of complexity, incorporating two or more colors (typically a red and black palette).

- **Composition and Symmetry:** There appears to be a deliberate and significant correlation between the decorative scheme, the fabric, the vessel morphology, and its intended function. In these types, high-precision

motifs are localized to the upper half or upper third of the vessel. However, small jars frequently feature a simple, solid monochromatic wash across the entire exterior.

- Plastic Decoration: Additional decorative techniques encompass applied “rope” motifs generated through finger-impressed patterns in diverse configurations.

Regarding the iconography and “design grammar” of these ceramics, the assemblage shares a broad stylistic framework with contemporaneous Mesopotamian types, although precise parallels are challenging to establish. This phenomenon -general stylistic affinity coupled with idiosyncratic detail- is likely attributable to localized production. This hypothesis is strongly corroborated by the identification of primary production evidence in the western sectors of Chogha Ahowan and Chogha Boichag (Javanmardzadeh, 2017: 99-116).



◀ Fig. 1: Location of the Mehran Plain within Iran, indicating the identified archaeological sites from the Urban Period (Javanmardzadeh, 2014: 20).

### Archaeological Sites

A total of eight sites within the Mehran Plain provide evidence pertinent to this chronological phase, comprising Chogha Ahowan, Chogha Boicheg, Chia Gap, Bahramabad, Mansourabad, Zarroush, Shameh Var, Ram-Rameh, and Cham Papi. Among these, three sites contain occupation layers from antecedent periods, whereas five represent newly established settlements. Significantly, these new settlements were founded on the periphery of the plain in zones devoid of prior habitation (Javanmardzadeh, 2014: 211). For the objectives of this research, four pivotal sites -Chogha Ahowan, Chogha Boicheg, Zarroush, and Bahramabad- were selected for comprehensive examination and sampling. During this era, Chogha Ahowan emerged as a paramount urban center, encompassing over 20

hectares and exerting hegemony over the entire plain. Evidence strongly implies that the site maintained extensive extra-regional interactions. The substantial expansion and development of Chogha Ahowan can likely be ascribed to its functional role as a regional nexus, facilitating connections with neighboring societies, including those in the Dehloran Plain and Mesopotamia (Javanmardzadeh, 2017: 99-116).

Surface surveys at Chogha Ahowan uncovered architectural remains of mud-brick and stone, alongside kilns and vitrified kiln slag. The kilns and slag are predominantly clustered in the southwestern sector, whereas architectural features are more prevalent in the central zone. The ceramic assemblage is characterized by:

- Buff Ware: Plain buff, plain purple, and painted varieties exhibit high density across the entirety of the site.
- Painted Buff Ware: These demonstrate a lower frequency relative to other types and are primarily concentrated in the central and southwestern sectors.
- Spouted Vessels: A higher density of spouted vessels was documented in the southern half of the mound.
- Bevelled Rim Bowls (BRBs): Although these iconic diagnostic vessels occur in relatively low proportions, their highest concentration is observed in the northern sector of the mound (Javanmardzadeh, 2014: 212).

Table 1: Characteristics of the study areas (Javanmardzadeh, 2014: 257). ▼

No.	Survey Code	Site Name	N	E	E (a.s.l)	Dimension (metres)	Elevation above the ground	Geographical Feature (distance/ Direction)
1	MS 022	Zarroush	609321	3667909	164	100×90	1	Kojan Cham river- 600 m. northwest
2	MS 027	Choghā Ahovān	613753	3670076	215	550×500	10.5	Kojan Cham river- 3200 m. west
3	MS 029	Chia Boicheg	612346	3662348	172	350×300	12.5	Close to Gavi River
4	MS 032	Bahrām Abad	607210	3662516	149	100×80	2.5	Badoleh stream- 1 km. North

The surface survey of Chia Boicheg yielded a diverse assemblage of material culture, encompassing plain and painted buff wares, plain and painted purple wares, vitrified (burnt) ceramics, fragments of gypsum storage jars, stone door sockets, grinding stones (querns), and clay sickles.

- Spatial Distribution: Painted buff wares exhibit a higher density within the elevated (northern) sector of the mound. Conversely, purple wares are distributed across the entire site, with a notable accumulation in the southeastern area.
- Stratigraphic Indicators: The southeastern sector also contains a

higher frequency of ash layers relative to other zones. On the northern slope, evidence of burning and thermally altered mud-brick walls is visible on the surface, whereas the southern sector reveals distinct remains of mud-brick architecture.

- Chronology: Predicated on ceramic analysis, a chronological span of 5300–2900 BCE is proposed, encompassing the Early, Middle, and Late Chalcolithic (Village Period) through the Proto-Urban and Urban periods (Javanmardzadeh, 2014: 213).

The surface of Zarroush is heavily scattered with brick kiln slag and brick fragments. However, the prehistoric findings are characterized by:

Ceramics: Plain and painted buff wares, alongside plain purple wares.

Lithic Industry: The lithic assemblage primarily comprises blades and micro-blades manufactured from dark gray chert (flint).

Chronology: Surface pottery indicates a timeframe of 3200–2900 BCE, corresponding strictly to the Urban Period (Javanmardzadeh, 2014: 214-215).

The survey at Bahramabad identified plain purple and buff wares, clay sickles, ground stone vessels, querns, and stone door sockets, along with various lithic artifacts. Analogous to Zarroush, the ceramic evidence suggests a relatively ephemeral occupation during the Urban Period, dated to approximately 3100–2900 BCE (Javanmardzadeh, 2014: 214-215).

### Petrographic Analysis

The provenance study of ancient ceramics is conducted through the petrographic analysis of thin sections and the examination of their inclusions (such as tempering agents). This method systematically investigates the origins of the clay and the tempers used, correlating them with the geographical location and geological characteristics of the study area (Noghani & Emami, 2012). The primary objective of thin-section petrography is to characterize clay-based materials by examining their microscopic properties. This is primarily achieved using a polarized light microscope (PLM). By transmitting polarized light through thin sections, two main components are identified: The clay matrix and Non-plastic inclusions.

Furthermore, this technique allows for the analysis of voids and pores, as well as observable details regarding surface treatments and finishing processes. The technical and physical attributes of the final product are identified through the type, frequency, and distribution of these features. Other observations derived from thin sections provide critical data

regarding the fabric, manufacturing technology, and provenance of the pottery (Peterson, 2009).

Petrographic studies are performed on microscopic thin sections. To prepare these sections, a small fragment of the ceramic sample is first detached using a precision diamond saw. The sample is then ground and polished to eliminate scratches and blade marks. Finally, the specimen is mounted onto a glass slide using epoxy resin (Quinn, 2013: 21). In this study, a total of 14 ceramic samples were selected for petrographic analysis from four key sites: Chogha Ahowan, Chogha Boicheg, Zarroush, and Bahramabad.



Fig. 2: Potsherds of the Mehran Plain's sites selected for petrographic and XRF analysis (Authors, 2023). ►

Sample 1 from Bahram Abad; the fabric and Mineralogical Composition: The fabric of Sample 1 from Bahram abad is characterized as a heterogeneous silty fabric. The primary constituents identified include quartz, calcite, chert fragments, iron oxides, and minor metamorphic rock fragments. The grain size of these inclusions is generally less than 0.5 mm.

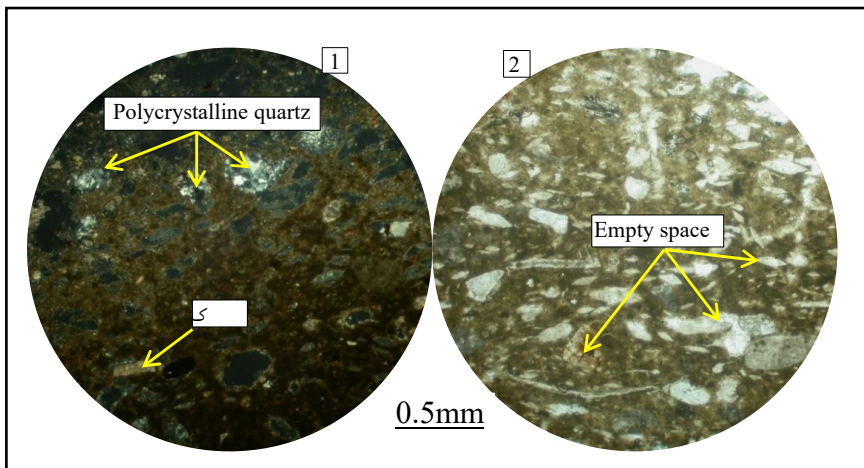
- Quartz: This is the most abundant mineral, accounting for approximately 5% of the total volume. It appears in both monocryſtalline (phenocryſt) and polycryſtalline forms, with morphologies ranging from angular to sub-rounded.

- Calcite: Distributed throughout the matrix as coarse-grained cryſtals, comprising about 3% of the fabric.

- Chert: Identified as coarse-grained fillers within the matrix, with a frequency of 3%.

- Metamorphic Fragments: Observed in trace amounts.

The ceramic matrix (groundmass) consists of a calcareous-clayey composition. A significant number of voids is present, characterized by an elongated and oriented morphology. A distinct preferred orientation (alignment) is observed among the inclusions and the elongated voids within the matrix. This microstructural feature is a diagnostic indicator of the potter's wheel technique, where the rotational force aligns the particles and air pockets during the shaping process.



◀ Fig. 1: Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Heterogeneous silty fabric exhibiting polycrystalline quartz associated with calcite.

◀ Fig. 2: Photomicrograph (Plane-Polarized Light - PPL), field of view: 2.7 mm. Heterogeneous silty fabric. Note the high frequency of elongated voids and their preferred orientation, indicating that the vessel was wheel-made (Authors, 2023).

The fabric of Sample 2 is characterized as a homogeneous silty fabric. The inclusion assemblage consists of quartz, calcite, chert fragments, and iron oxides. Similar to Sample 1, the inclusion size remains below 0.5 mm.

- Chert Fragments: These function as coarse-grained fillers within the matrix, accounting for approximately 3% of the total volume.

- Quartz: Present in both monocrystalline (phenocryst) and polycrystalline forms. The grains exhibit morphologies ranging from angular to sub-rounded, comprising about 2% of the sample volume.

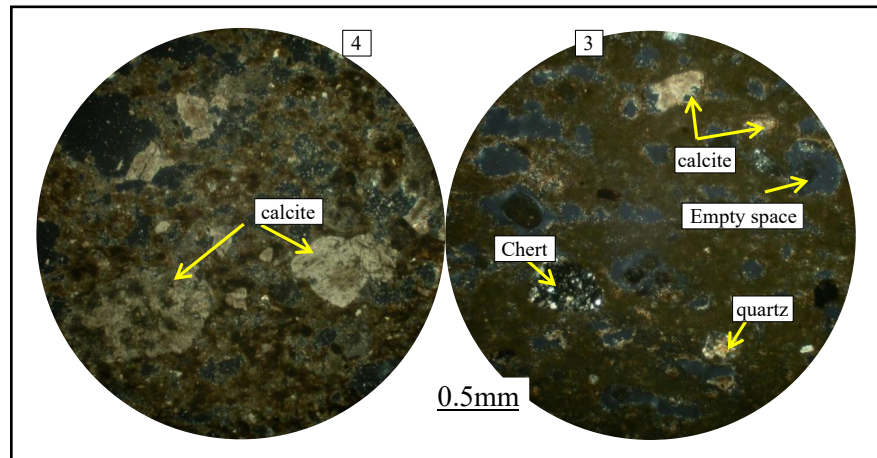
- Calcite: This constituent appears in two distinct forms: integrated within the clay matrix and as coarse-grained individual fragments.

The groundmass (matrix) exhibits a homogeneous calcareous-clayey composition. Compared to the previous sample, the matrix shows a more uniform distribution of fine-grained particles. The presence of voids is relatively high, indicating a specific level of porosity in the ceramic body (Fig. 3 & 4).

The Sample 3 from Bahram Abad is exhibiting a porphyritic texture within a heterogeneous matrix. The primary mineralogical constituents include calcite, quartz, and iron oxides. The inclusion size varies significantly, ranging from microns to 1 mm.

**Fig. 3: Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Homogeneous silty fabric. Primary inclusions including quartz, chert, and calcite are visible within the matrix. Note the relatively high frequency of voids (Authors, 2023). ▶**

**Fig. 4. Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Porphyritic texture. Characterized by the presence of abundant coarse-grained calcite fragments embedded within the finer-grained ceramic groundmass (Authors, 2023). ▶**



- **Calcite:** This is the predominant mineral, appearing in two forms: as coarse grains and integrated within the groundmass. Notably, it occurs as sparry calcite (coarse crystals) within the fabric.

- **Quartz:** Observed as monocrystalline phenocrysts with morphologies ranging from angular to sub-rounded, comprising approximately 2% of the sample volume.

- **Mineralogical Note:** Unlike the previous samples, this specimen is devoid of chert fragments.

- **Matrix:** The groundmass consists of a homogeneous calcareous-clayey composition.

**Zarroush: Sample 1** The fabric of this sample is categorized as silty with a homogeneous matrix. The inclusion assemblage is more complex, containing quartz, calcite, chert, iron oxides, and fragments of metamorphic and igneous rocks. The grain size of these constituents is generally less than 0.5 mm.

- **Chert Fragments:** These function as coarse-grained fillers, with a frequency of 2%.

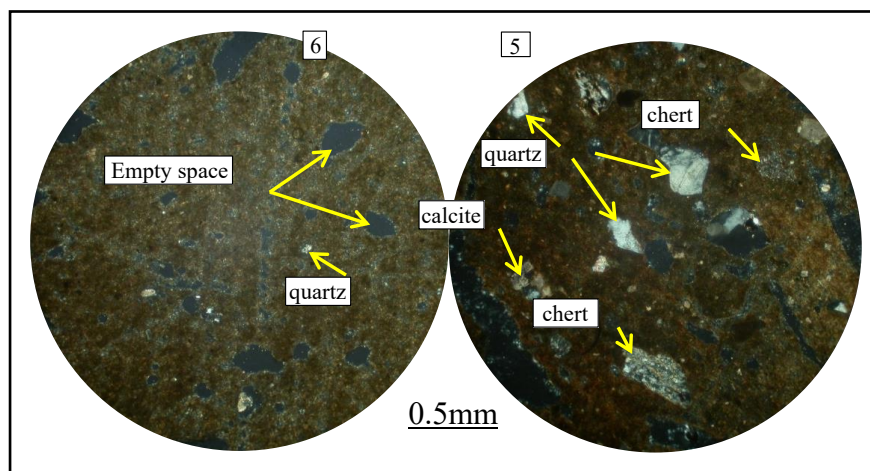
- **Quartz:** Present in both monocrystalline and polycrystalline forms, with angular to sub-rounded margins, accounting for about 2% of the volume.

- **Calcite:** Appears both as a constituent of the matrix and as coarse individual fragments.

- **Metamorphic & Igneous Fragments:** Identified as trace inclusions, providing a distinct mineralogical signature for this site.

- **Matrix:** Exhibits a homogeneous calcareous-clayey composition (Fig. 5 & 6).

**Zarroush: Sample 2:** The fabric is characterized as silty with a homogeneous matrix. The inclusions consist of quartz, calcite, chert,



◀ Fig. 5. Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Silty fabric featuring fragments of quartz, metamorphic rock, chert, and calcite. The groundmass is homogeneous with a calcareous-clayey composition (Authors, 2023).

◀ Fig. 6. Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Silty fabric with a highly homogeneous matrix. Note the limited distribution of calcite and quartz. Voids (porosity) appear as dark areas within the fabric (Authors, 2023).

and iron oxides. A distinguishing feature of this sample is its extremely fine-grained nature, with inclusion sizes generally remaining below 20 microns. All constituents are finely dispersed and well-integrated into the groundmass.

- Calcite: Comprises 2% of the volume.
- Quartz: Comprises 1% of the volume.
- Chert: Occurs in trace amounts (less than 1%).
- Matrix: The groundmass is highly homogeneous and calcareous in composition.

Zarroush: Sample 3: This sample exhibits a silty fabric with a homogeneous matrix. The mineralogical suite is more diverse, including quartz, calcite, mica, iron oxides, and fragments of metamorphic and igneous rocks. The grain size of these inclusions is less than 0.5 mm.

- Quartz: Identified in both monocrystalline (phenocryst) and polycrystalline forms, with angular to sub-rounded margins. It is the most abundant inclusion, accounting for approximately 5% of the sample volume.

- Thermal Alteration (Calcite): A critical observation in this sample is the thermal decomposition of calcite. Due to high firing temperatures, the primary calcite has been destroyed, leaving behind characteristic calcite ghosts (rims or halos).

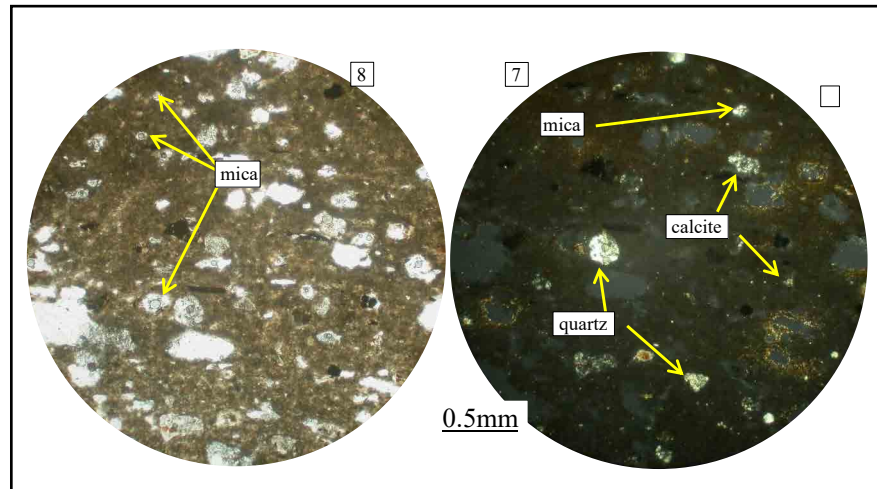
- Mica (Biotite): Fragments of biotite (black mica) are present but appear darkened/opaque, another indicator of the firing process.

- Matrix: Unlike previous samples, the matrix is non-calcareous and exceptionally homogeneous. The sample is devoid of chert fragments (Fig. 7 & 8).

The fabric of Sample 1 from Chia Boichegis is characterized as porphyritic with a heterogeneous calcareous matrix. The inclusion suite

**Fig. 7. Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Silty fabric with a strictly homogeneous, non-calcareous matrix. Visible features include quartz, biotite (thermally altered/darkened), and calcite ghosts (remnants of decomposed calcite). Voids (porosity) appear as dark areas within the fabric (Authors, 2023). ▶**

**Fig. 8. Photomicrograph (Plane-Polarized Light - PPL), field of view: 2.7 mm. Silty fabric. This image represents the same field of view as Figure 7, captured under plane-polarized light. In this mode, voids and porosity are clearly distinguishable as bright (translucent) areas within the matrix (Authors, 2023). ▶**



primarily consists of calcite, quartz, and iron oxides. The grain size of these constituents exhibits a wide range, from a few microns to 1 mm.

- **Calcite:** This is the dominant mineral, accounting for approximately 20% of the total sample volume. It occurs in two distinct forms: sparry calcite (coarse-grained crystals) and micritic calcite (fine-grained crystals) within the fabric.

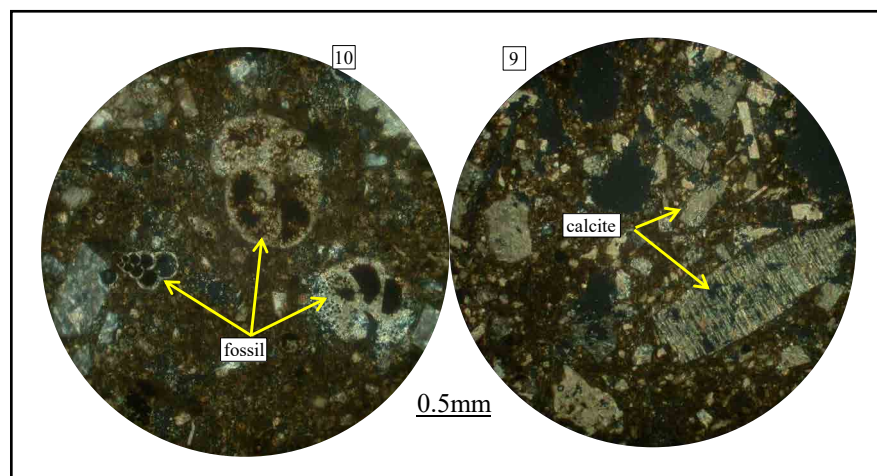
- **Bioclasts (Fossils):** A significant feature of this sample is the presence of fossil fragments embedded within the matrix, providing important clues regarding the sedimentary origin of the clay.

- **Quartz:** Identified as monocrystalline phenocrysts with angular to sub-rounded margins, comprising about 1-2% of the volume.

- **Mineralogical Note:** Similar to Bahramabad Sample 3, this specimen is devoid of chert fragments and possesses a markedly heterogeneous calcareous-clayey matrix (Fig. 9 & 10).

**Fig. 9: Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Porphyritic texture showing abundant and large calcite fragments embedded in the ceramic groundmass (Authors, 2023). ▶**

**Fig. 10. Photomicrograph (Plane-Polarized Light - PPL), field of view: 2.7 mm. An example of bioclasts (fossils) present within the ceramic matrix (Authors, 2023). ▶**



The fabric of Sample 2 is classified as silty with a homogeneous matrix. The identified inclusions include quartz, calcite, chert fragments, and iron

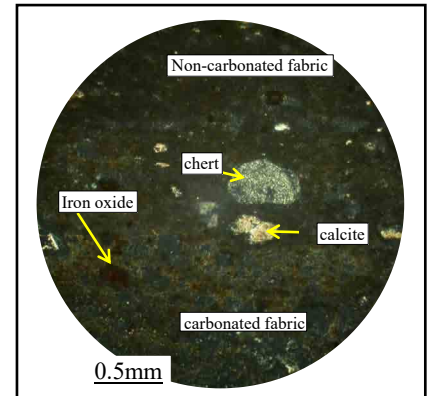
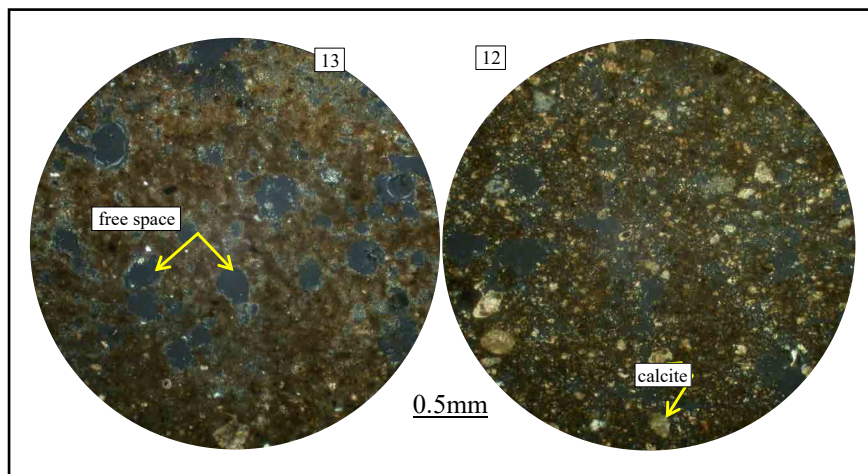
oxides. The grain size of these constituents is consistently below 0.5 mm.

- Chert Fragments: These appear as sparsely distributed inclusions within the matrix, accounting for approximately 1% of the total volume.
- Quartz: Present in both monocrystalline (phenocryst) and polycrystalline forms. The grains exhibit morphologies ranging from angular to sub-rounded, comprising about 2% of the sample volume.
- Calcite: This constituent is observed both as coarse-grained fragments and integrated within the groundmass.
- Matrix: The groundmass displays a homogeneous calcareous-clayey composition, showing a uniform mixture of clay and micro-crystalline carbonates (Fig. 11).

The fabric of Sample 3 from Chia Boicheg is classified as silty with a heterogeneous matrix. The mineralogical constituents include calcite, quartz, and iron oxides. The inclusion size is generally less than 0.5 mm.

- Calcite: This mineral is abundant, constituting approximately 15% of the total sample volume.
- Quartz: Occurs as monocrystalline (phenocryst) forms, sparsely distributed within the ceramic groundmass.

A significant observation is the distinct microstructural variation from the center to the edge of the sample. As one moves toward the rim (periphery), the fabric transitions into a fine silty texture that is markedly devoid of calcite inclusions. This indicates a non-uniform distribution of tempering agents during the shaping process (Fig. 12 & 13).



▲ Fig. 11. Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Silty fabric. Visible inclusions include chert fragments, calcite, and iron oxides embedded within the ceramic matrix. The distinction between the calcareous and non-calcareous phases of the groundmass is clearly discernible (Authors, 2023).

◀ Fig. 12. Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Abundant calcite inclusions distributed within the ceramic groundmass (Authors, 2023).

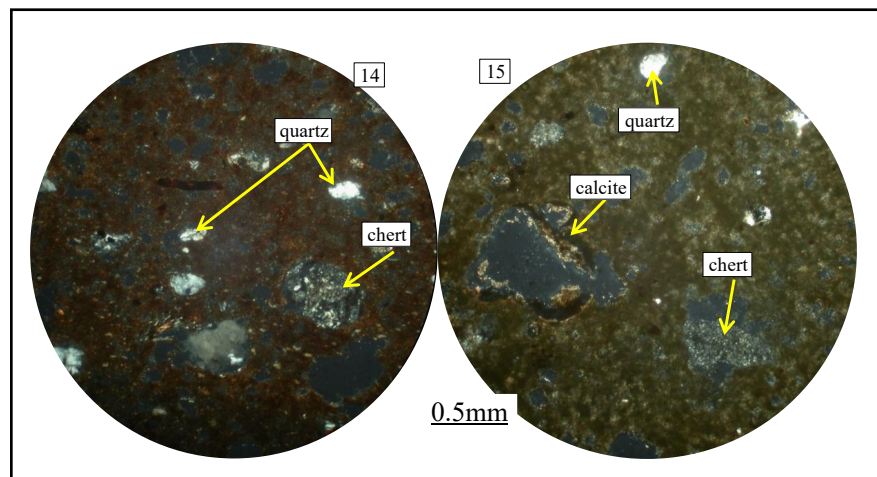
◀ Fig. 13. Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. The rim (periphery) of the sample, which is devoid of calcite inclusions and exhibits a homogeneous, uniform matrix. Dark areas represent voids (porosity) within the groundmass (Authors, 2023).

The fabric of Sample 4 is classified as silty with a homogeneous, non-calcareous matrix. The mineralogical constituents include quartz, calcite, chert fragments, metamorphic rock fragments, and plagioclase feldspar. The grain size of these inclusions is generally below 0.5 mm.

- Quartz: Present in both monocrySTALLINE (phenocryst) and polycrySTALLINE forms, with angular to sub-rounded margins, comprising about 4% of the sample volume.
- Chert Fragments: These occur as sparsely distributed inclusions within the matrix, with a frequency of 2%.
- Calcite: Present as coarse-grained fragments, accounting for 1% of the total volume.
- Metamorphic Fragments & Plagioclase: Identified in trace amounts within the ceramic groundmass.
- Matrix: The groundmass is characterized by a red-colored, homogeneous, non-calcareous composition, indicating an oxidizing firing atmosphere and distinct clay sourcing (Fig. 14 & 15).

**Fig. 14.** Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Sparsely distributed chert fragments, quartz, and iron oxides within the ceramic groundmass. The inclusions are low in frequency, and the matrix exhibits a distinct red color with a non-calcareous composition (Authors, 2023). ▶

**Fig. 15.** Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. The ceramic groundmass features a calcareous-clayey composition and is highly homogeneous. Chert fragments, calcite remnants, and quartz phenocrysts are sparsely distributed (Authors, 2023). ▶

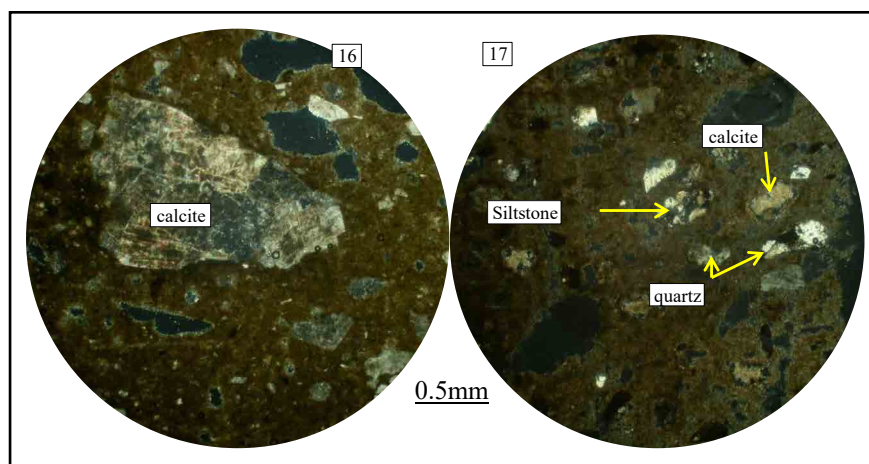


Both samples from Chogha Ahowan exhibit a silty fabric with a homogeneous matrix. The mineralogical composition is remarkably similar, consisting of quartz, chert fragments, calcite, and siltstone. The inclusion size is consistently below 0.5 mm.

- Chert Fragments: Distributed sparsely within the matrix, accounting for approximately 3% of the volume in both samples.
- Quartz: Identified in both monocrySTALLINE (phenocryst) and polycrySTALLINE forms, with angular to sub-rounded margins, comprising about 2% of the sample volume.
- Calcite & Thermal Alteration: A critical observation in both specimens is the thermal decomposition of calcite, resulting in the preservation of only characteristic calcite ghosts (rims). This indicates high firing temperatures.
- Sedimentary Rock Fragments: Siltstone fragments are present in trace amounts within the ceramic groundmass.
- Matrix: The groundmass consists of a homogeneous calcareous-clayey composition.

### Comparative Note

Sample 2 is petrographically identical to Sample 1, suggesting a standardized production process or a common clay source for these vessels (Fig. 16 & 17).



◀ Fig. 16. Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. The ceramic groundmass features a calcareous-clayey composition and is highly homogeneous. Siltstone fragments (a sedimentary rock), calcite ghosts, and quartz phenocrysts are sparsely distributed (Authors, 2023).

◀ Fig. 17. Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Abundant large calcite fragments are found within the ceramic groundmass. Voids (porosity) appear as dark areas (Authors, 2023).

The sample 3 from Chogha Ahowan exhibits a porphyritic texture within a homogeneous matrix. The primary mineralogical constituents are calcite, quartz, and iron oxides. Inclusion sizes range from a few microns to 1 mm.

- Calcite: This is the dominant mineral, comprising approximately 10% of the sample volume. It occurs in two forms: sparry calcite (coarse-grained crystals) and micritic calcite (fine-grained crystals) within the groundmass.
- Quartz: Present as monocrystalline phenocrysts with morphologies ranging from angular to sub-rounded, accounting for 1–2% of the volume.
- Mineralogical Note: The sample is devoid of chert fragments. The ceramic groundmass features a heterogeneous calcareous composition.
- Comparative Note: Petrographically, this sample is similar to Bahramabad Sample 3 and Chia Boicheg Sample 1.

Sample 4 from Chogha Ahowan displays a silty fabric with a homogeneous matrix. The inclusion suite includes quartz, chert fragments, and calcite. Inclusion sizes are generally less than 0.5 mm.

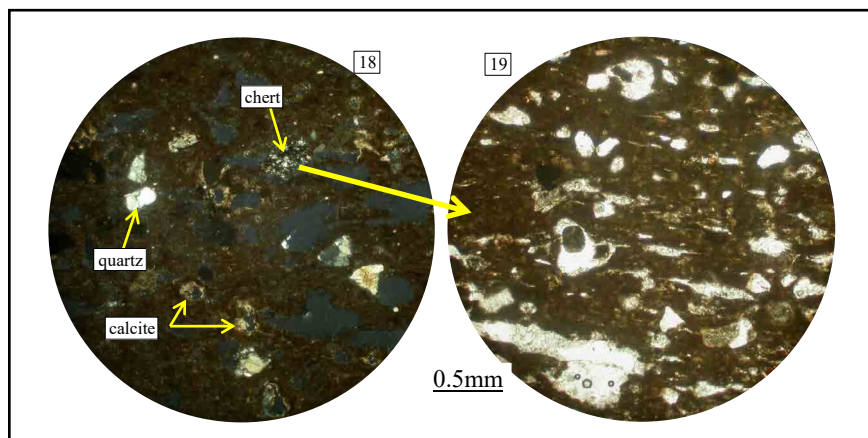
- Chert Fragments: Distributed sparsely within the matrix, accounting for 3% of the volume.
- Quartz: Identified in both monocrystalline (phenocryst) and polycrystalline forms, with angular to sub-rounded margins, comprising about 2% of the volume.
- Thermal Alteration (Calcite): Like Samples 1 and 2, the calcite has undergone thermal decomposition, leaving behind only characteristic calcite ghosts (rims).

- **Technological Indicators:** The groundmass exhibits a distinct preferred orientation (alignment) of inclusions and elongated voids. This microstructural feature is a definitive indicator that the vessel was wheel-made.

- **Matrix:** The groundmass consists of a calcareous-clayey composition (Fig. 18 & 19).

**Fig. 16:** Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. The ceramic groundmass features a calcareous-clayey composition and is highly homogeneous. Siltstone fragments (a sedimentary rock), calcite ghosts, and quartz phenocrysts are sparsely distributed (Authors, 2023). ▶

**Fig. 17:** Photomicrograph (Cross-Polarized Light - XPL), field of view: 2.7 mm. Abundant large calcite fragments are found within the ceramic groundmass. Voids (porosity) appear as dark areas (Authors, 2023). ▶



Based on the study of three ceramic samples from Tepe Bahram Abad, it can be concluded that Samples 1 and 2 are similar in terms of the constituent components, paste, and matrix composition. The primary difference between them lies in the relative abundance of each component. In contrast, Sample 3 differs completely in composition from the other two. In this sample, sparry calcite fragments were used as temper, and it exhibits a coarse (porphyritic) texture. In the other two samples, chert fragments were employed, and both display a silty (fine-grained) texture.

The three ceramic samples from Tepe Zarroush differ entirely from one another. Samples 1 and 2 have a carbonate–clay composition. In Sample 1, various fragments of quartz, calcite, and chert are observed, whereas Sample 2 is almost devoid of inclusions and shows a completely homogeneous texture. Sample 3 from Zarroush has a non-carbonate paste composition; the calcite originally present has been eliminated due to firing. Additionally, biotite (mica) appears burnt brown because of the heat generated during the firing process.

Among the samples from Tepe Chia Boicheg, Samples 1 and 3 are compositionally similar, both containing abundant calcite fragments. It should be noted that the size of the inclusions in Sample 1 is considerably larger than those present in the paste of Sample 3. Sample 2 has a carbonate–clay paste that differs completely from Samples 1, 3, and 4. Sample 4 has a non-carbonate composition and contains minor amounts of metamorphic rock fragments and plagioclase, which were not observed in the other three

studied samples. Sample 16 appears to have a completely different origin compared to the other samples analyzed from Tepe Chogha Boicheg

The three samples from Tepe Chogha Ahowan are compositionally similar, with their main differences lying in the relative percentages of constituent components. However, Sample 2 from Chogha Ahowan differs from the others. This sample lacks chert and instead contains various calcite fragments used as temper. It is comparable to Sample 1 from Tepe Chogha Boicheg and Sample 3 from Tepe Bahram Abad.

For ease of reference to the petrographic results, the findings are presented in Table 2. This table is based on the petrographic study of ceramics. The first row lists the ceramic constituents, while the first column provides the name and number of each sample separately. The presence of a given mineral in a sample is indicated by an asterisk, its absence by a dash (-), and trace amounts are marked as (tr).

Table 2. Results of petrographic study of pottery from Bahram Abad, Zarroush, Chogha Boicheg and Chogha Ahowan. Guide: Qz(Clean)=Clear quartz and phenocryst. Qz(Cloudy)=Cloudy quartz and polycrystalline. Plg=Plagioclase and feldspar. Fe-oxid=Iron oxide. Cc=Calcite. P-Rock=Igneous rock (plutonic). V-Rock=Igneous rock (volcanic). M-Rock=Metamorphic rock. S.R=Sedimentary rock (Authors, 2023). ▼

No. of Sample	Qz (Clean)	Qz (Cloudy)	Plg	Fe-oxid	Cc	Mica	Chert	P.Rock V.Rock	M.Rock	S.R	Texture
Bahram Abad-1			-			-		-	Tr	-	Heterogeneous silt
Bahram Abad-2			-			-		-	-	-	silt
Bahram Abad-3		-	-			-	-	-	-	-	Porphyry
Zarroush		-	-			-		tr	Tr	-	silt
Zarroush		-	-			-		-	-	-	silt
Zarroush		-	-			-		-	Tr	-	silt
Chogha Boicheg		-	-			-	-	-	-	-	Porphyry
Chogha Boicheg			-			-		-	-	-	silt
Chogha Boicheg		-	-			-	-	-	-	-	silt
Chogha Boicheg			tr			-		-	Tr	-	silt
Chogha Ahovan			-			-		-	-	Tr	silt
Chogha Ahovan			tr			-		-	-	Tr	silt
Chogha Ahovan		-	-			-	-	-	-	-	Porphyry
Chogha Ahovan			-			-		-	-	-	silt

### X-ray Fluorescence (XRF) Analysis of the Mehran Plain Samples

Chemical analysis constitutes one of the most reliable methods for identifying the elemental composition and concentration of elements in archaeological materials, such as ceramics, glass, and metal objects (Sarhadi-Dadian et al., 2015; Bieber et al., 1976; Marghussian et al., 2017).

In this method, an X-ray beam is directed at the unknown samples, causing atomic excitation and the emission of secondary X-rays. By determining the wavelength or energy of the secondary X-rays, the constituent elements

can be identified. Specifically, the X-ray beam emitted from the X-ray tube strikes the sample, bombarding the atoms and ejecting inner-shell electrons. The replacement of these electrons by others from higher energy levels results in the emission of characteristic X-rays. This phenomenon is analogous to bombarding the sample with electrons (Golestani-Fard et al., 2010: 93). For the X-ray fluorescence analysis, 5 grams of powder was separated from each ceramic specimen for preparation and analysis. The results of this analysis are presented semi-quantitatively in Table 3.

As indicated in Table 3, most of the elements identified are present in trace amounts.

#### 1. Silicon Dioxide ( $\text{SiO}_2$ ) and Iron Oxide ( $\text{Fe}_2\text{O}_3$ )

Bahramabad Samples 1 and 2 exhibit the highest concentrations of silicon dioxide ( $\text{SiO}_2$ ). This chemical finding is corroborated by the petrographic analysis, which identified abundant chert fragments within these samples. Furthermore, these samples also show the highest concentrations of iron oxide.

#### 2. Aluminum Oxide ( $\text{Al}_2\text{O}_3$ )

The concentration of aluminum oxide ( $\text{Al}_2\text{O}_3$ ) is uniform across all samples. This consistency is directly linked to the composition of the clay raw material used in the ceramic production process.

#### 3. Calcium ( $\text{Ca}$ )

Chogha Boicheg Sample 1, Zarroush Sample 1, and Chogha Boicheg Sample 3 display significantly higher concentrations of calcium ( $\text{Ca}$ ) compared to the other specimens. Petrographic examination of these samples reveals that this high calcium content is due to the presence of abundant calcite inclusions and a calcareous-clayey matrix.

Table 3: The semi-quantitative Analytic results (Authors, 2023). ►

Sample No.	Chogh.B18	Zarvash1	Chogh.B9	Zarvash4	Bahram Abad23	Bahram Abad24
Na <sub>2</sub> O	1.015	1.011	1.184	1.013	1.299	1.352
MgO	0.380	0.772	0.429	0.633	0.711	0.688
Al <sub>2</sub> O <sub>3</sub>	3.504	3.202	3.381	3.854	4.270	4.025
SiO <sub>2</sub>	19.745	18.431	19.343	21.852	25.657	22.843
P <sub>2</sub> O <sub>5</sub>	0.955	0.932	0.974	0.820	1.006	1.172
SO <sub>3</sub>	1.439	2.146	2.336	0.890	0.486	0.877
Cl	0.042	0.124	0.069	0.101	0.328	0.243
K <sub>2</sub> O	2.463	1.785	2.005	2.090	3.008	1.676
CaO	47.272	46.962	47.509	44.795	38.743	43.963
TiO <sub>2</sub>	1.277	1.062	1.236	1.277	1.455	1.321
V <sub>2</sub> O <sub>5</sub>	0.036	0.037	0.037	0.046	0.045	0.051
Cr <sub>2</sub> O <sub>3</sub>	0.052	0.042	0.038	0.046	0.107	0.066
MnO	0.128	0.175	0.130	0.177	0.220	0.213
Fe <sub>2</sub> O <sub>3</sub>	9.653	10.266	9.573	11.282	14.907	13.333
CoO	<dl	<dl	<dl	<dl	0.008	0.013
NiO	0.028	0.042	0.030	0.047	0.078	0.064

CuO	0.007	0.013	0.007	0.009	0.021	0.168
ZnO	0.041	0.041	0.042	0.041	0.045	0.042
Ga	0.004	0.004	0.004	0.004	0.004	0.003
Ge	<dl	<dl	<dl	<dl	<dl	<dl
As2O3	0.002	0.003	0.002	0.002	0.003	0.003
Se	0.000	0.000	0.000	<dl	<dl	0.000
Br	0.001	0.002	0.001	0.001	0.002	0.002
Rb2O	0.012	0.011	0.011	0.009	0.011	0.006
SrO	0.550	0.479	0.521	0.496	0.384	0.472
Y	0.006	0.007	0.006	0.007	0.008	0.007
ZrO2	0.035	0.037	0.037	0.040	0.051	0.041
Nb2O5	0.004	0.004	0.004	0.004	0.004	0.004
Mo	<dl	0.001	0.000	0.001	0.000	0.000
Ag	<dl	<dl	0.001	0.002	0.001	0.005
Cd	0.003	<dl	<dl	<dl	0.000	0.003
SnO2	0.004	0.003	0.003	0.002	0.003	0.009
Sb2O5	0.005	0.003	0.004	0.003	0.003	0.008
Te	0.003	<dl	<dl	<dl	0.000	0.006
I	0.008	0.004	0.005	0.001	0.005	0.007
Cs	<dl	0.007	<dl	<dl	<dl	<dl
Ba	0.082	0.115	0.100	0.096	0.088	0.051
La	<dl	<dl	<dl	<dl	<dl	<dl
Ce	0.031	<dl	<dl	<dl	<dl	<dl
Pr	0.012	0.003	0.005	0.006	0.003	0.005
Nd	0.025	0.013	0.014	0.016	0.016	0.011
Er	<dl	<dl	<dl	<dl	<dl	<dl
Yb	<dl	<dl	<dl	<dl	<dl	<dl
Hf	<dl	<dl	<dl	<dl	0.000	<dl
Ta2O5	0.028	0.027	0.029	0.027	0.028	0.033
WO3	0.032	0.009	0.034	0.021	0.046	0.048
Hg	<dl	<dl	<dl	<dl	<dl	<dl
Tl	0.000	<dl	0.000	0.000	0.000	0.000
PbO	0.004	0.006	0.007	0.003	0.005	0.004
Bi	<dl	<dl	<dl	<dl	<dl	<dl
Th	0.002	0.002	0.002	0.002	0.002	0.002
U	0.001	0.001	0.001	0.001	0.001	0.002
l.o.i	11.105	12.216	10.883	10.278	6.936	7.149

## Conclusion

The final centuries of the fourth millennium BCE marked a pivotal era characterized by the emergence of comprehensive political entities and the inception of writing in southern and central Mesopotamia, as well as parts of southwestern Iran. This period, spanning approximately 3200–2900 BCE, is recognized as the Urban Period or the Jemdet Nasr Period. While the process of sedentarization in Mesopotamia began in earlier periods, the transformation of settlement patterns and the rapid expansion of cities in central and southern Mesopotamia are explicitly witnessed during the Jemdet Nasr period.

**1. Cultural Context and Ceramics:** Concurrent with this development in Mesopotamia, a distinct culture emerged in southwestern Iran and the

Iranian Plateau (ca. 3100 BCE), known as the Proto-Elamite cultural tradition. In southwestern Iran, cultural unity with southern Mesopotamia is clearly corroborated by ceramic types and seal impressions (Matthews, 1992: 201). The ceramics identified from the Jemdet Nasr period in the Mehran Plain are similar to Mesopotamian examples. These ceramics can be broadly divided into two groups: coarse and fine wares. The vessels are light brown or buff in color, devoid of any decoration, and are primarily observed in the form of unhandled jars with rough bodies.

**2. Petrographic and Geological Insights:** The study area is rich in geological resources, featuring various types of limestone, sandstone, marl, gypsum, evaporite minerals, shale, and fragments of chert and chalcedony within its sediments and rock outcrops. The geomorphology and climatic conditions of the region allow for the occurrence of rocks with distant origins, such as metamorphic and igneous fragments, in archaeological sites and riverbeds, which are incorporated into the fabric of some ceramic samples.

- **Fabric Analysis:** The ceramic fabric of the region is either coarse (porphyritic) or fine-grained (silty). Quartz minerals, in both monocrystalline and polycrystalline forms, along with calcite, constitute the primary inclusions. Calcite is also present within the clay matrix. In some ceramics, fossil remnants are visible; however, it appears that many of the shaped voids in the samples from the Mehran Plain are the result of fossil decomposition from the clay matrix.

- **Tempering Agents:** Chert and calcite fragments, abundantly available in the plain, were utilized as tempering agents (fillers) in these ceramic samples. Metamorphic, igneous, sedimentary rocks, and plagioclase are present in trace amounts.

**3. Firing Technology and Provenance:** Calcite minerals exist in both micro-crystalline (micrite) and coarse-crystalline (sparite) forms. Since calcite decomposes at temperatures above 800°C, it serves as a thermal indicator in ceramic studies. With the exception of Chogha Ahowan Samples 1, 2, and 4, and Zarroush Sample 3, where calcite has been thermally decomposed leaving only characteristic calcite ghosts, the presence of calcite in the remaining samples indicates that the firing temperature was below 800°C.

- **Production Techniques:** The microstructure of several samples reveals a flow texture, likely resulting from the use of the potter's wheel. Color variations within the vessels are not related to their composition but are rather due to oxidizing or reducing conditions and oxygen availability during the firing process.

• Local Production: Based on the geological studies of the Mehran Plain and the results of laboratory analyses conducted on samples collected from four sites, along with strong evidence of local ceramic production in the western sections of Chogha Ahowan and Chogha Boicheg, it can be concluded that the majority of these samples are of local origin. The minor differences between the southwestern Iranian samples and the Mesopotamian examples are attributed to this local production.

Geographic Locations and Archaeological Sites (Mehran Plain):

1. Pashmin
2. Jebal-e Hamrin
3. Konjān Cham
4. Gāvi
5. Changouleh
6. Choghā Ahowān
7. Choghā Boycheg (Chogha Buicheg)
8. Chiā Gap (Chia Gab)
9. Bahrām Ābād
10. Mansour Ābād
11. Zarroush
12. Shama Ver
13. Remah
14. Cham-e Pāpi
15. Inclusion: The fragment of a rock or mineral enclosed within another rock.
16. Epoxy Stone Glue (Epoxy Resin Adhesive): A two-component, resin-based adhesive used for bonding stone pieces in industries, residential applications, construction, and facade work.
17. Glass Slide: A rectangular glass plate used for mounting thin sections.
18. X-ray Fluorescence (XRF): A technique used for elemental analysis of materials.

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### Author Contributions

All authors have had equal participation.

### Conflict of Interest

The Authors, while observing publication ethics in referencing, declare the absence of conflict of interest.

### References

- Bieber, A. M., Brooks, D. W., Harbottle, G. & Sayre, E. V. (1976). "Application of multivariate techniques to analytical data on Aegean ceramics". *Archaeometry*, 18(1): 59-74. <https://doi.org/10.1111/j.1475-4754.1976.tb00145.x>
- Javanmardzadeh, A., (2017). "The Mehran Plain during the Early Urban Period". *Journal of Archaeological Studies*, 7(12): 99-116. (In Persian).
- Javanmardzadeh, A., (2014). *Analysis of Settlement Patterns and Regional Interactions in the Mehran Plain from the Sixth Millennium to the Early Third Millennium BCE*. Unpublished Doctoral Dissertation, Faculty of Literature and Human Sciences, University of Tehran. (In Persian).
- Javanmardzadeh, A., (2015). "Proto-Historical Interactions between Southwestern Iran and Mesopotamia: Evidence and Characteristics". In: *Proceedings of the 5th International Conference of Young Archaeologists*, Tehran: Iranology Foundation and University of Tehran. (In Persian).
- Javanmardzadeh, A. & Darabi, H., (2012). Mehran Plain Archaeological Project: Settlements of the Proto-Urban and Urban Periods". *Journal of Archaeological Research of Iran*, 2(3): 81-96. (In Persian).
- Sarhadi-Dadian, H., Pourzarghan, V., Moradi, H. & Razani, M. (2015). "A Preliminary Analysis of the Indigenous Nature of Shahr-i Sokhta Buff Ware Using Semi-Quantitative XRF Elemental Analysis". *Journal of Archaeometry*, 1(1): 47-54. (In Persian). <https://doi.org/10.29252/jra.1.1.47>

- Peterson, S. E. & Betancourt, P. P., (2009). *Thin Section Petrography of Ceramic Materials*. In *Instap Archaeological Excavation Manual 2*. Philadelphia: Instap Academic Press. <https://doi.org/10.2307/j.ctt3fgvbq>
- Quinn, P. S., (2013). *Ceramic Petrography: The Interpretation of Archaeological Pottery & Related Artefacts in Thin Section*. Oxford: Archaeopress. <https://doi.org/10.2307/j.ctv1jk0jf4>

تحلیل پتروگرافی و XRF سفال‌های دوره جمدهت نصر  
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## چکیده

منطقه جنوب غرب ایران در مطالعات باستان‌شناسی ایران در ادوار مختلف و به‌ویژه دوره‌های آغازتاریخی و شهرنشینی اهمیت بسیار ویژه‌ای دارد. دشت مهران در استان ایلام از جمله مناطقی است که دارای مواد فرهنگی هم‌افق و مشابه نمونه‌های جمدهت نصر است. براساس یافته‌های زیستگاهی، می‌توان دشت مهران را در این دوره، تابعی از تغییرات زیستگاهی بین‌النهرین به حساب آورد. برای درک دوره آغازشهرنشینی که سرآغاز بزرگ‌ترین و پیچیده‌ترین تغییرات سیاسی-اقتصادی و اجتماعی است و در جنوب غربی ایران هم‌چنان ناشناخته باقی مانده، تعداد ۱۴ قطعه سفال دوره جمدهت نصر محوطه‌های دشت مهران را که طی کاوش و بررسی‌های میدانی جمع‌آوری شده و مورد مطالعه قرار گرفته است، جهت انجام آزمایشات انتخاب شدند. این پژوهش با هدف آگاهی یافتن و فرض این مسئله که سفال نوع جمدهت نصر دشت مهران به صورت محلی تولید می‌شده، یا این‌که توسط متخصصین بین‌النهرینی تولید می‌شده و یک محصول وارداتی بوده است، انجام شده است. شواهد تولید سفال در چغآهوان و چغابویچگ، به‌ویژه تولید محلی سفال‌های دشت مهران را تأیید می‌کند. در تمام نمونه‌های مورد مطالعه دشت مهران، کانی کلسیت به صورت ریز بلور (میکرایت) و درشت بلور (اسپارایت) وجود دارد. نتایج آنالیز XRF نیز با یافته‌های پتروگرافی مطابقت دارد. در این نمونه‌ها، کلسیت در اثر حرارت از میان رفته و تنها هاله‌ای از آن باقی مانده است؛ وجود کلسیت در باقی نمونه‌ها نشان می‌دهد که درجه پخت سفال‌ها کمتر از ۸۰۰ درجه سانتی‌گراد بوده است. در نهایت براساس مطالعات و بررسی‌های زمین‌شناسی دشت مهران و نتایج آنالیز آزمایشگاهی صورت‌گرفته، می‌توان بیان کرد که سفال‌ها تولید داخلی و محلی داشته‌اند و مربوط به خود دشت هستند؛ هرچند سبک و فرم و تکنیک تولید مشترک با گونه‌های هم‌زمان بین‌النهرینی خود است؛ چراکه اثبات این فرض نیاز به مطالعات و آزمایشات تکمیلی تأسیسات تولید سفال و هم‌چنین سفال‌های دست‌نخورده و برج‌ها دارد.

کلیدواژگان: دوره جمدهت نصر، دشت مهران، پتروگرافی، XRF، جنوب غربی ایران.

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