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Laboratory Characterisation of Dalma Period Ceramics from Tepe Gheshlagh (Eastern Central Zagros, Iran)

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Abstract

Dalma was a pivotal culture during the 5th millennium BCE, located in the Northwest and Central Zagros regions of Iran. Excavation at Tepe Gheshlagh, a major site in the Dalma Centre of the Talvar Valley in Bijar County, between the Eastern Central Zagros and the Southern Lake Urmia Basin, revealed a sequence of habitation that spans the Early, Middle, and Late Chalcolithic periods. While previous research hinted at interactions between these two cultural spheres, there was a lack of information regarding intermediary centres. Radiocarbon determinations placed the earliest settlement at Gheshlagh, characterised by the Dalma tradition, dating back to 5500–5000 BCE. To gain a deeper understanding of the Dalma pottery manufacturing process, laboratory studies were conducted to identify the texture, constituents, and provenance of the sherds from the site. Among the assemblage, two sherds of Ubaid type were found to differ structurally from the typical local pottery, *viz*. Dalma Painted Ware. As a result, XRF, XRD, and petrography techniques were applied to investigate the pottery industry and the utilised compounds. A total of twelve sherds were singled out for XRF / XRD analyses, while 15 others were analysed by petrography. The XRD tests identified silica, calcite, quartz, iron, aluminium, Biotite, and mica (muscovite) as the main phases present in the samples. The XRF analysis confirmed the presence of Silica, calcite, aluminium, and mica constituent elements. Furthermore, petrographic analysis detected quartz, chert, calcite, siltstone, iron, and plagioclase, which aligned with the findings from the XRF / XRD measurements. Additionally, petrography identified two pieces as being imports from other regions, thus pointing to the local inhabitants' extra-regional ties.

Keywords: East of Central Zagros, Dalma Period, Early Chalcolithic Period, Petrography, XRF/XRD.

Article Type: Research Article[1]

Introduction

Tepe Gheshlagh is situated in the Talvar Valley, Bijar County, Kurdistan Province (Sharifi 2020). A major reason for the mound's prominence is an over 14 m thick deposit dating from the different phases of the Chalcolithic period. This deposit includes the Dalma culture at the lowest layer (9 metres thick with 4 architectural phases), mid-Chalcolithic in the middle (0.3 metres thick, lacking architecture), and Godin VII type (late Chalcolithic) material in the upper level (5 metres thick with 3 architectural phases), forming a long, uninterrupted sequence. Following this, there was a long hiatus before the establishment of Iron III occupations, represented by two architectural phases (Motarjem and Sharifi 2014; 2018). Given Gheshlagh's importance during the Chalcolithic period, the present paper will specifically examine the Dalma-type pottery found at the site. By around 5500 BCE, the Talvar Valley provided suitable environmental conditions for permanent settlement, making Gheshlagh Tepe favourable for long-term occupations by the Dalma culture, which, according to radiocarbon determinations, persisted continuously between 5500

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and 3600 BCE. Research suggests close contacts during the Early Chalcolithic with northwestern regions, particularly with Dalma Tepe (Hamlin 1975), as well as Anatolia (Tekin 2005; Mellaart 1961; Garrard *et al*. 1996), the Caucasia and the Republic of Azerbaijan (Bakhshaliyev 2017; Lyonnet and Guliyev 2010; Narimanov 1987; Chataigner *et al*. 2010; Bakhshaliyev *et al.* 2020; 2021; Marro 2022; Kuliyeva and Bahşeliyev 2018), and inspirations from the northern Mesopotamian traditions (Oates 1983; Jasim 1983; Tsuneki and Miyake 1998). The pottery exhibits several affinities with Pisdeli (Dyson and Young 1960; Dyson 1968), Godin (Young 1966; 1969; Young and Levine 1974), and Seh Gabi (Henrickson 1983). In the Late Chalcolithic period, the site was predominantly influenced by the Godin VII culture, as evidenced by the complete absence of Chaff-faced ware (Sharifi and Omrani 2022).

Manufacturing technology, particularly the assessment of firing temperature, is a crucial aspect examined through the archaeothermometry technique (Rasmussen *et al*. 2012; Sanjurjo-S´anchez and Montero Fenollo´s 2014). The characteristics of archaeological pottery can be influenced by factors such as the grain sizes and composition of raw materials, firing procedure (maximum temperature, rate, and duration of heating, redox atmosphere), and any weathering processes that occurred during the burial period (Montana 2016; Prudêncio 2008; Tite 2008). Petrography, a widely used method in geology and archaeology, is utilised to observe and identify the mineralogical composition, fabric, and characteristics of pottery sherds (Casale *et al*. 2020).

This study will focus solely on analysing the Dalma Painted Ware from Gheshlagh, as the most confusing question regarding the Early Chalcolithic pertains to the technical aspects of pottery manufacturing. There is a noted lack of technological knowledge regarding Dalma pottery in eastern Central Zagros, highlighting the need for systematic archaeometric approaches, laboratory analyses, and interdisciplinary studies. The constituent elements of the Gheshlagh samples will be characterised using XRF/XRD analyses and petrography. The compounds and elements present in the fired paste can provide significant insights into kiln temperature and the firing process of the original vessels. Petrography aims to identify the components and the compositional variances among the samples. The present study mainly aims to specify the relative frequency of individual components, the firing temperature based on the existing minerals, and finally, the sources from which the raw materials were procured. Therefore, the present study seeks to clarify the cultural attributes and structure of early Chalcolithic (Dalma) pottery in the eastern Central Zagros and examine two pieces of Ubaid-type pottery from Gheshlagh. Key questions addressed will include the origins of the pottery, structural comparisons, differences in the frequencies of the elements and oxides, and the types of applied minerals. We will analyse the ware types of the Dalma pottery, with the hypothesis that the Dalma Painted Ware examples were produced locally, while the two Ubaid-type pieces were likely imports.

Tepe Gheshlagh

The Central Zagros region has intrigued scholars since the start of archaeological research in Iran. Notable projects include those at Godin (Young 1969) and Seh Gabi (Levin and Young 1986:17; Henrickson 1983:478; Henrickson 1985:66; McDonald 1979) projects. The initial investigations of the Chalcolithic period concentrated on Dalma Tepe (Hamlin 1975; Abedi and Sharifi 2021) and later the Central Zagros (Motarjem and Sharifi 2014), revealing the Dalma pottery traditions.

As mentioned earlier, the longest attested period at Gheshlagh corresponds to the Dalma culture, as illustrated in Figure.1. The site is particularly well-suited for an in-depth study of the relevant deposits related to the cultural changes during the Dalma period. This is because the thickness of the coeval deposit at the three mounds of Seh Gabi was reportedly merely slightly more than 2 metres. In contrast, the low elevation of Dalma Tepe (ca. 3–4 metres) and its seemingly rather short-lasting occupations (Hamlin 1975) further bolster the significance of Tepe Gheshlagh due to its notably thick deposits, as shown in Figure.2 (Sharifi 2020). The earliest inhabitants of Gheshlagh were likely familiar with the Dalma culture and established a long-lasting settlement on the mound, encouraged by the favourable climate and environment provided by the Talvar River during the Early Chalcolithic period, as indicated in Table 1.

The earliest occupation level at Gheshlagh was formed directly on virgin soil and represents the initial settlement of the site. The pottery from this period belongs to the Dalma culture and includes both impressed and painted varieties. In the first place, the affinities between the pottery traditions

of Tepe Gheshlagh and Dalma Tepe are evident, particularly in their decorative patterns, forms, and the prevalence of painted ware. A ubiquitous pattern found at Gheshlagh is the geometric motifs that continue the abstract motifs of Hajji Firuz (Voigt and Dyson 1992: Figure.18; Voigt 1983:145-146-14.). Similar Motifs have been identified in the excavated assemblages from Dalma Tepe (Hamlin 1975) and Lavin (Hejabari Nobari *et al.* 2012: Figure.8). The framed geometric lozenges at Gheshlagh (Figure.3, nos. 1-2) have parallels in the Zagros region (Henrickson 1992: Figure. 20), at Seh Gabi mound B (Levine and Young 1986: Figure.4), Pisdeli in Azerbaijan (Dyson and Young 1960:25), and Lavin (Hejabari Nobari *et al*. 2012: Figure.8). Beyond modern Iran, lozenges are also discovered in Mesopotamia, notably at Tell Songor of the Ubaid period (Jasim 1985: Figure.254) and Tell Arpachiyah during the Halaf period (Hijjara 1997: Figure.36:185, pl. VIII:188). Overall, Gheshlagh's pottery tradition adheres to both regional and extra-regional models while displaying a few local idiosyncrasies. To further examine Gheshlagh pottery, laboratory studies were carried out on the Dalma Painted Ware specimens and the two (Ubaid-type) pieces that appeared distinct within the assemblage.

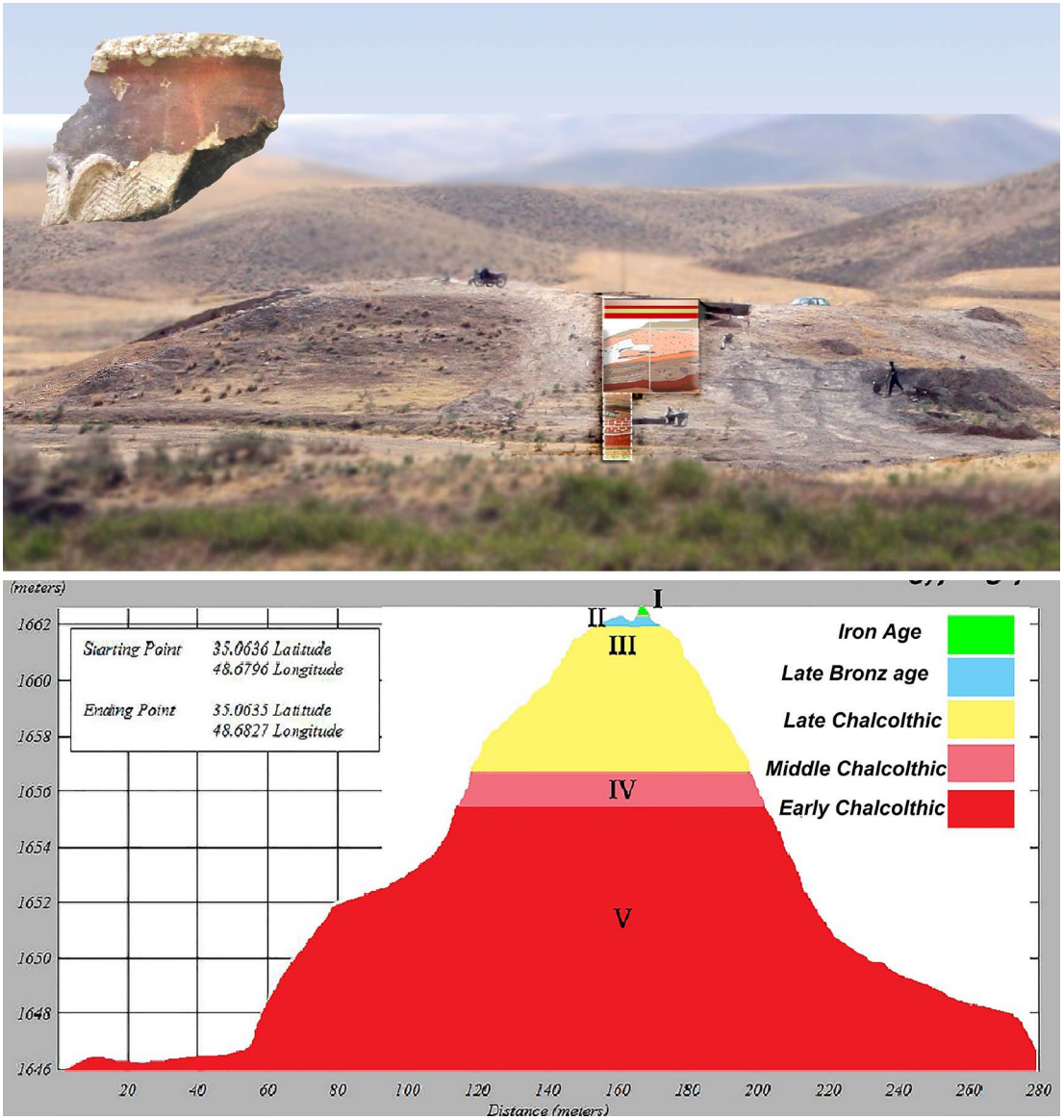


Figure. 1: *Tepe Gheshlagh: profile of settlement sequence.*

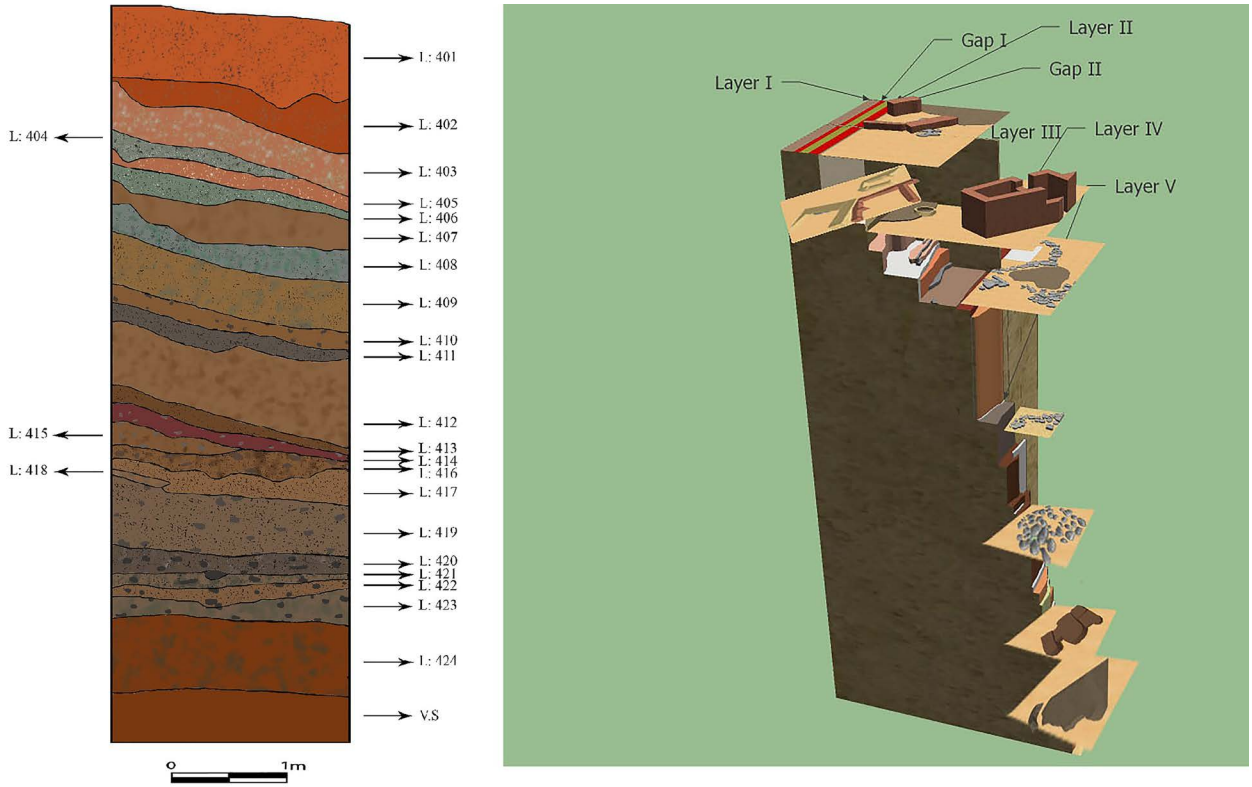


Figure. 2: *Tepe Gheshlagh: sections and construction phases (After: Sharifi 2018)*

Table. 1:*Tepe Gheshlagh: Chronological chart of the periods*

Sequence of Gheshlagh	Period	Date/ BCE
Gheshlagh III	Late Chalcolithic (Godin VII)	3600±220
Gheshlagh III	Late Chalcolithic (Godin VII)	3850±280
Gheshlagh IV	Pisdeli/Seh Gabi	3915±270
Gheshlagh IV	Pisdeli/ Seh Gabi	3960±290
Gheshlagh V	Early Chalcolithic (Dalma)	5000±305
Gheshlagh V	Early Chalcolithic (Dalma)	5500±250

Research Questions and Hypothesis

Archaeological data indicate that the Dalma culture was the predominant culture in the region during the 5th millennium BCE. In an effort to better understand this prehistoric culture, researchers studied the associated pottery.

Dalma Painted Ware represents a significant pottery tradition of the Early Chalcolithic period. Its analysis involves interdisciplinary sciences alongside archaeological inquiries. Thus, understanding the technological facets of pottery production can open the way for a better understanding of the materials involved from technical and technological perspectives since the Dalma culture spanned a vast territory (Henrickson and Vitali 1987) and was the dominant culture in northwest Iran and the Central Zagros region during that time. This paper attempts to pinpoint the major technical and structural aspects of the coeval pottery. Central questions include: What are the composition and structure of Dalma pottery at Gheshlagh? What was the manufacturing process, and what oxides exist in the paste? What are the structural differences and similarities? Additionally, what were the firing temperatures and, most importantly, what were the origins of the raw materials- were they locally produced or imported? To address these questions, XRF/XRD analyses and petrographic studies were conducted on a sample of excavated material from Gheshlagh. Based on the

circumstantial evidence and analysis results, it is hypothesised that the examples of Dalma Painted Ware are domestic, while the two Ubaid types (depicted in Figure.3, nos. 14-15) are non-native due to discrepancies between their raw materials and local resources.

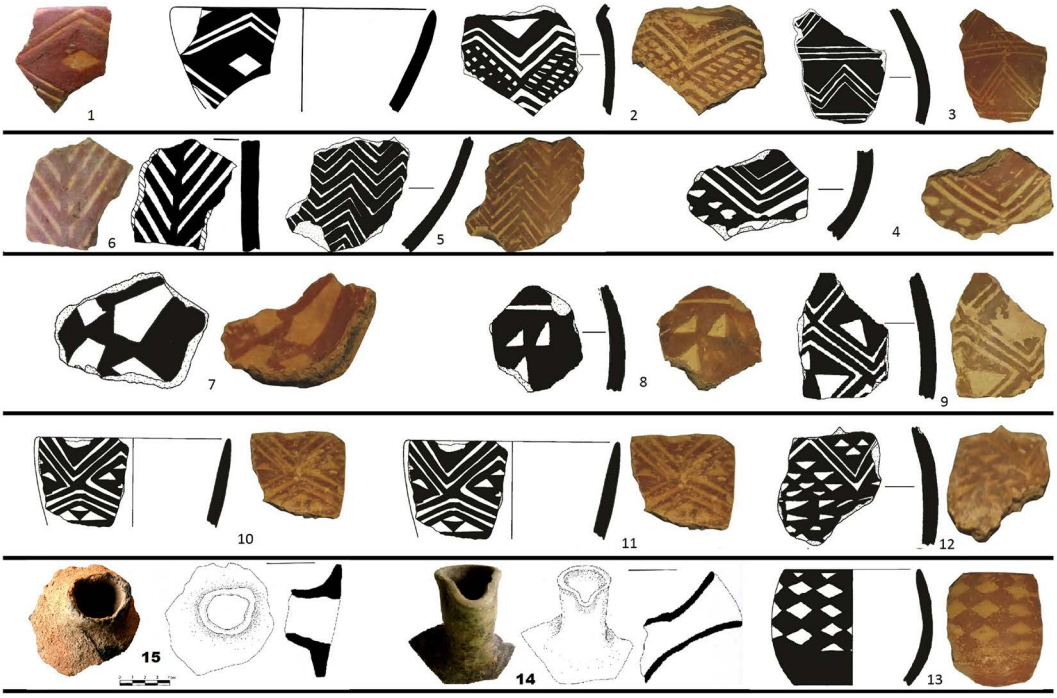


Figure. 3: *Analysed ceramics before cutting.*

Gheshlagh from Geographical and Geological Perspectives

The uplands of Iranian Kurdistan Province are divided into two western and eastern parts. The eastern part, known as the Sanandaj region, forms a volcanic chain characterised by a mountain barrier comprised of metamorphic and sedimentary rocks that girdle high, hilly tablelands (Mahmoudi 1973). Volcanic cones are prominent features in Bijar, which ranks among the major young volcanic regions of Iran. The volcanicity, typically manifested as central eruptions along an arched linear band, has led to the formation of conic peaks (Mahmoudi 1973: 3). The Quaternary magmatic rocks were developed as stratocones during alternating effusive and explosive phases, and they are in a desulfurisation stage today. Lava flows were emitted in several short-interval phases (Razavi and Sayyareh 2010: 151). The remnants of volcanic cones are discernible as pumice fragments scattered throughout the region. Bijar is situated in the Sanadaj-Sirjan zone (Berberian and King 1981), which is part of central Iran and represents a highly active tectonic zone that has witnessed substantial metamorphism and magmatism phases (Stocklin 1968). The oldest rocks attested include slate and Cretaceous volcanic rocks, while younger varieties are primarily Miocene limestones overlaid by a conglomerate basement, leading to the region's loftiest elevations. Additional materials found include quartz, calcite, and plagioclase—elements that have also been detected in the fabric of the ceramics from Gheshlagh.

Research Method

The present study on the Gheshlagh pottery employs XRF, XRD, and petrography approaches. XRF analyses will identify the general composition of the pottery fabric, while XRD characterises the crystalline components present in the thin sections. The samples were collected from the lower deposit of Gheshlagh, specifically in Dalma and Ubaid styles. A total of 12 sherds were chosen for XRF/XRD analyses and 15 pieces for petrography. The analyses were performed using a Seifert XRD T2T powder diffractometer at 30 mA and 40 kV. The data on the crystalline phases were obtained using Xpert HighScore Plus software and the PDF2 database.

History of Research

Using petrographic studies, Tonoike (2010) examined the Dalma pottery of northwest Iran and the Central Zagros. Additionally, Tala'I (1984) conducted a structural analysis of the Urmia-style pottery from Kul Tepe. Inquiry into the Early Bronze (EBA) ceramics from Chaldoran was another interdisciplinary study (Afsharinezhad *et al*. 2017). Regarding the EBA, Mason and Cooper (1999) carried out petrographic examinations on pottery from Godin Tepe IV. Northworthy EBA laboratory analyses include studies at Barveh (Sharifi 2025; Barani *et al.* 2024), Tepe Pirtaj (Sharifi and Omrani 2022), and Sonqor Koliyaie Plain, all located in the Central Zagros (Heyderian *et al*. 2020), which show connections with northwest Iran. Furthermore, petrographic studies from Arsalan Tepe in Turkey have been reported (Fragnoli and Manuelli 2023).

Petrographic Analysis

Thin sections from a sample of 15 sherds were examined using a James Swift polarising microscope at 4x and 10x magnifications. The results are outlined in Table 2. The petrographic analysis builds on mineralogical attributes, texture, and elemental composition of a given specimen.

Microscopic Study

Difference in Paste Colour

For microscopic examination, the specimens were divided into the following categories by paste colour:

1.Bicoloured,
2.Single-coloured (red or brown), and
3.Cream-coloured (as shown in Figure.4, no. 6).

The analysed samples exhibited a dark red appearance, with their interiors covered in a dark red slip. Both bicoloured and single-coloured varieties displayed frequent voids in their cross-sections.

As a ubiquitous mineral of all specimens, quartz was detected in the two monocrystalline and quartzite morphologies at relative abundances varying from 5% to 20%. Another commonly found component was calcite, often observed in coarsely crystalline form or sparite within the paste, as detailed in Table 2.

Table. 2: *Results of the petrographic study of the pottery from Tepe Gheshlagh*

** = present, - = absent, tr = trace*

Abbreviations: Qz(Clean)(Krbrz 1983) = transparent quartz and phenocryst; Qz(Cloudy) = cloudy and polycrystalline quartz; Fe-oxid = iron oxide; Cc = calcite; Plg = plagioclase; Mica = mica; AM&PX = amphibole and pyroxene; Chert = clast of chert rock (After:Whitney and Bernard 2010)

N. S	Qtz (Clean)	Qtz (Cloudy)	Plg	Am & Px	Fe-oxid	Mica	Cal	V.R & P.R	Chert	S.R & Silt Stone	Texture
Gh-1	*	*	trace	-	*	*	*	-	-	*	fine-grained silty
Gh-2	*	*	-	-	*	*	*	-	-	-	fine-grained silty
Gh-3	*	*	trace	tr	*	-	*	-	-	-	homogeneous silty
Gh-4	*	*	*	-	*	-	*	-	-	*	heterogeneous silty
Gh-5	*	*	-	-	*	-	*	-	-	-	heterogeneous silty
Gh-6	*	*	-	-	*	-	*	-	-	-	homogeneous paste
Gh-7	*	*	-	-	*	-	*	-	*	*	heterogeneous silty
Gh-8	*	*	-	-	*	-	*	-	-	-	heterogeneous silty
Gh-9	*	*	-	-	*	-	*	-	-	-	heterogeneous silty
Gh-10	*	*	-	-	*	-	*	-	*	-	Silt
Gh-11	*	*	*	-	*	-	*	-	-	-	heterogeneous silty
Gh-12	*	*	*	-	*	-	*	-	-	-	Silt
Gh-13	*	*	-	*	*	-	*	-	*	*	silty, porphyry
Gh-14	*	*	tr	*	*	tr	*	-	-	*	Silt
Gh-15	*	*	tr	tr	*	-	*	-	-	-	Silt

In the bicoloured pastes, the margin of the matrix exhibited little or no calcite content, which appeared lighter in colour than the core due to exposure to higher heat. The highest concentration of calcite was found in the darker fraction of the paste. Iron compounds, seen in a dark red colour, were attested, as was plagioclase, albeit in very small quantities. Additionally, clasts of metamorphic rocks were present in some cases (see Figure.4, no. 4b). All specimens exhibited an abundance of voids in various shapes, including spherical and oval. In most cases, these voids likely formed due to the loss of vegetal temper during firing. A few cases had developed a porous texture as a result of these voids. Sample 6 notably stood out due to its cream-coloured fabric (see Figure.4, no. 6).

In contrast, the rather poorly sorted heterogeneous fabrics contained components of varying sizes. Minerals such as quartz, calcite, and iron oxide were abundantly present. According to the microscopic structure outlined in Table 2, the examined pieces exhibited a silty (fine crystal) or silty-porphyry texture (as seen in sample 13). As seen in Table 1, all the specimens invariably contained calcite (micrite), quartz (phenocryst), and iron oxide. Some samples also revealed fragments of siltstone, chert, and amphibole, setting them apart from the others.

Sample 1: Non-carbonate fabric with a fine-grained silty texture. Quartz is present in the margin of the dark slip, with trace amounts of plagioclase. Sample 2: Bicoloured paste, with a light margin and darker core. Sample 3: Homogeneous silty texture with abundant quartz. The letter "c" indicates traces of a vegetal temper that vanished during the firing, leaving only a channel (thin, elongated void). Sample 4: Heterogeneous silty texture containing calcite, quartz, and clasts of metamorphic rock. Sample 5: Bicoloured pastes. Sample 6: Homogeneous paste featuring frequent voids and quartz inclusions.

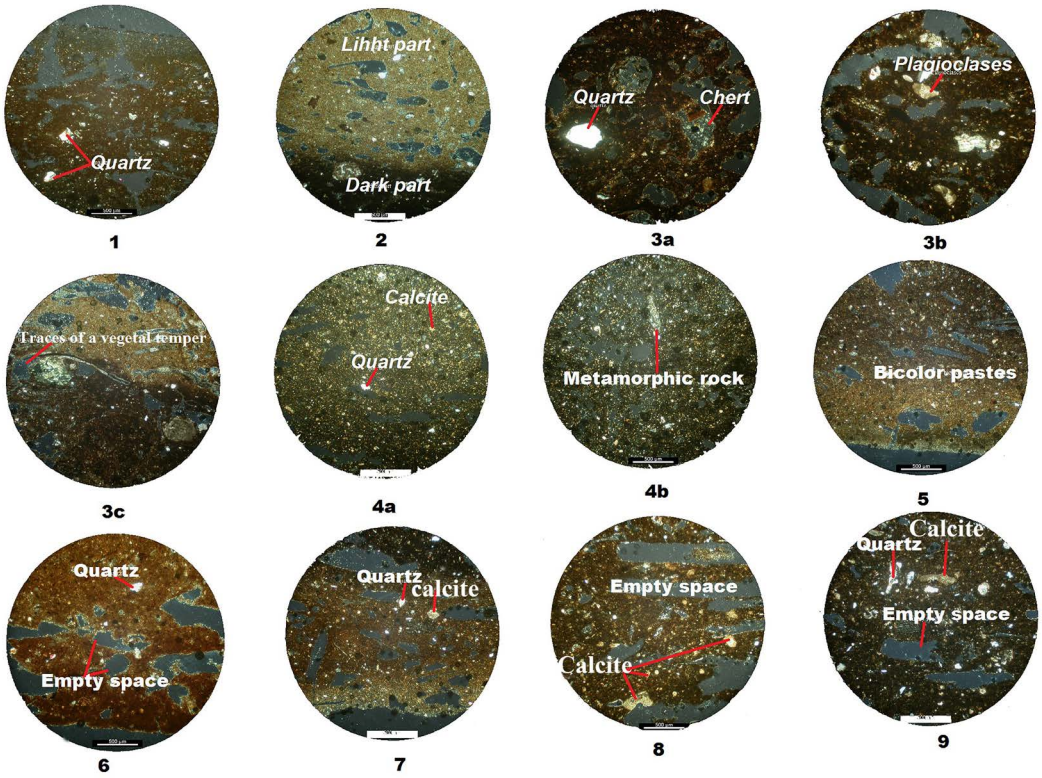


Figure.4: *Photomicrographs of the studied pottery sherds, (After: Research Centre for Conservation of Cultural Relics)*

Difference in Composition

The specimens were categorised into two main categories based on their composition: heterogeneous and homogeneous. Both categories displayed a fine-grained texture. Homogeneous fabrics demonstrated excellent sorting, with grain sizes not exceeding 100µm. Quartz, either as phenocryst or quartzite, was the dominant mineral, with some instances of polycrystalline quartz.

Sample 7: Bicoloured paste composed of quartz and calcite as the main constituents. Observed using XPL light, at 4x magnification.

Calcite is central to any thin-section analysis of ceramic bodies, serving as a thermal indicator. It is destroyed at temperatures exceeding 800 °C (Shepard 1956). Given the presence of calcium carbonate in the regional sedimentary deposits, the absence of calcite in several specimens may suggest that the original vessels were ostensibly fired at higher temperatures, and its presence would indicate lower temperature ranges (Noghani *et al*. 2010).

Sample 6: This specimen forms a discrete group due to its unique composition. The light cream and completely homogeneous paste contains quartz and iron compounds, lacking carbonate, which suggests it was likely exposed to higher temperature ranges. Abundant voids coexist with quartz crystals (Emami and Noghani 2013; Riederer 2004).

Sample 7: This sample has a heterogeneous silty texture and a non-carbonate fabric, comprised of minerals such as calcite, quartz, clasts of metamorphic rock, and iron compounds. Calcite constitutes over 20% by volume, with quartz as a major element. The matrix has a relatively porous appearance.

Samples 8 and 9: Heterogeneous silty texture and non-carbonate paste, with significant calcite and quartz contents. Sample 10 (see Figure.5): Non-carbonate and homogeneous paste with frequent voids and quartz. Sample 11: Similar fabric to sample 10, featuring a dark slip layer on the margin. Observed using XPL at 4x magnification (image width: 2.7mm).

Sample 11 exemplifies single-coloured pastes with no carbonate content, indicating a firing temperature above 800 °C. In such specimens, quartz was the primary paste constituent, comprising relative abundances between 5% and 10%. They also contained minute quantities of phyllosilicate minerals and plagioclase.

Sample 12: Non-carbonated and homogeneous paste exhibiting numerous voids filled with single-crystal and fine-grained quartz. Observed using XPL at 4x magnification (image width: 2.7mm).

In the thin section, Sample 13, as shown in Figure.5, displays a silty, porphyritic texture. This heterogeneous texture contains inclusions of fine crystal siltstone, quartz, iron oxide, phyllosilicate minerals (such as mica), and amphibole, which float within a fine-grained matrix. The most abundant component in this sample is quartz, present as both phenocrysts and polycrystalline, with the former being the most abundant type. The mineral comprises about 15–20% of the sample's volume. Iron oxide appears next, accounting for around 10% and exhibiting a red-to-dark colour. Stone fragments, representing residual siltstone and fine-grained sandstone, make up less than 5% by volume. Calcite manifests as fine crystals within the matrix. Recurrent voids were left by the vegetal temper. A dark layer outlining the specimen's margin represents a slip applied to the original vessel's surface. Beneath this layer lies a compact, fine crystal area.

Sample 13: Photomicrograph, a thin section featuring polycrystalline quartz in the middle ground, alongside various chert minerals and iron oxide embedded in the fine crystal matrix. Viewed under XPL. Voids appear as dark spots under this light.

Sample 13c-d: Photomicrograph, a thin section viewed under PPL. Voids occur in light colour. The dark layer in the lower foreground represents the slip that overlays a compact layer. Clasts of siltstone coexist within the fine crystal matrix, along with quartz and iron oxide. In the background, the thin dark slip film emerges alongside the underlying layer.

Apart from the Dalma Painted Ware pieces, the excavated assemblage from Tepe Gheshlagh contains two pieces of Ubaid-type ceramics in the form of lenticular vessels with a short opening, as shown in Figure.3, nos. 14-15, which parallel Gurdil's findings (2005:311). Petrographic analyses demonstrated that these two non-native pieces likely arrived at the site as imported items.

Sample 14: Vessel with a long neck and pouring opening, as shown in Figure.3, no. 14. This specimen shows a light brown margin, which relates to the firing process of the vessel. The silty texture (fine crystal matrix) dominates, with well-sorted constituents including several inclusions that make up the fabric:

Calcite: It is seen as micrite and fine crystals in the matrix and accounts for about 10–15% of the fabric's total volume.

Quartz: The phenocryst crystals make up about 5–10% of the total volume. No polycrystalline quartz was detected. Another attested mineral is

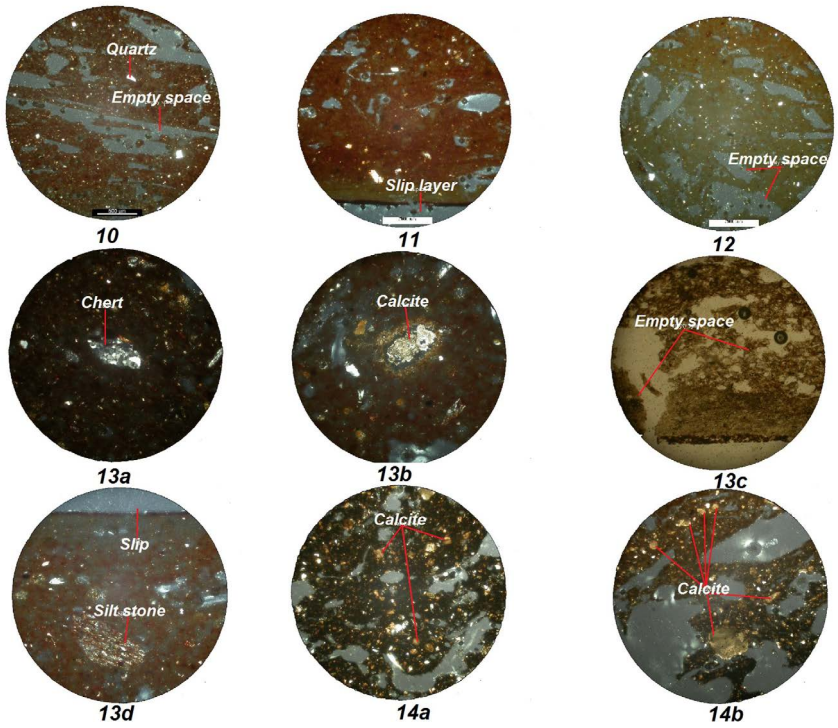


Figure. 5: *Photomicrographs of the studied pottery sherds. Figure width: 2.7mm.*
(After: Research Centre for Conservation of Cultural Relics)

iron oxide. Notably, the high carbonate content in the matrix markedly distinguishes this specimen from the previous examples.

Sample 14a: The photomicrograph shows a thin section, viewed under XPL, illustrating the silty texture and the minerals in the matrix (indicated by the arrow), including calcite. In addition, quartz is visible in a light colour. The dark appearance of the matrix was mainly caused by the firing conditions.

Sample 15: This sample is derived from a vessel with a pear-shaped rim, characteristic of Ubaid forms. Ubaid wares are generally well-fired (Berman 1994:24), and the Ubaid-type vessel from Gheshlagh adheres to this quality. In the cross-section, it is fairly fine-grained with extremely rare voids. Observations on the thin section depict a fine-grained or silty texture. The inclusions within the fine-grained matrix mainly consist of calcite, appearing both as sparite and to a lesser extent as micrite, and making up about 10–15% of the paste's total volume. Quartz, seen as phenocrysts, comprises about 5–10%. Iron oxide serves as another significant component. The clay matrix features a significant carbonate content, distinguishing it from other Painted Red Ware examples due to its calcite-rich paste combined with clay minerals.

XRD Analysis

The XRD method uses an X-ray with a specific wavelength to specify the space lattice in a crystal structure, allowing for the direct identification of the chemical compounds. This method complements petrography and is used for phase analysis (Pollard *et al*. 2007). The XRF technique was also applied to gain a deeper insight into the pottery industry and the compounds used. Analysis of ceramic bodies will shed light on their production processes. The XRD analysis seeks to identify the crystal lattice within ceramic bodies. Here, XRD tests were conducted on pottery from Gheshlagh to ascertain possible structural variations and examine the constituent elements through instrumental analysis methods. The attested crystalline phases are in agreement with the observations from microscopic petrography. A most notable result of these tests concerns documenting the overall firing degree based on the minerals formed at high temperatures during the firing (Emami 2012). The XRD tests identified various elements, as listed in Table 3. The primary phase identified was silicon oxide (quartz), followed by calcium carbonate (calcite). Several clay minerals were detected in the matrices of all specimens, including sodium aluminium, silicate, and quartz.

These compounds evince that soils derived from metamorphic rocks (SiO_2) contributed to the paste preparation, alongside calcareous soils (Ca, Al). The detection of SiO_2 confirms the presence of silicon oxide. The main constituent elements of the limestone include inclusions like silica (sio_2), iron oxide (Fe_2O_3), magnesium oxide (MgO), and aluminium oxide (Al_2O_3) (Jensen *et al.*2013).

Since all these compounds were detected in the analyses, one can conclude that the raw material used for the paste was of limestone soil type. Furthermore, the pastes from all 12 specimens share the same types of elements and composition.

Mica (muscovite) was detected in Samples 1 and 2, and biotite in Samples 7, 11, and 12. Some of these compounds, such as muscovite and vermiculite, were integral parts of the original soil resources.

The ubiquitous presence of silicon oxide is clearly documented in Table 3, which chronicles the major elements identified in this study.

Table. 3: *Results of XRD Analysis.*

(After: Conservation and Restoration Laboratory, Research Institute of Cultural Heritage and Tourism).

Sample no.	Phases identified	sample	Chemical formula	Scale Factor
1	Silicon Oxide + Iron + calcite + Sodium +Aluminium +Silicate+ Muscovite	Dalma Pottery	Si O_2+ Fe2.00+ Ca C O_3+ Na+Al+si	0.971
2	Silicon Oxide+ calcite Potassium Aluminium Silicate Muscovite		Si O_2+ Ca (C O_3)+ K Al Si_3 O_8+ Si12.00 +Al12.00 K4.00 +O48.00 H0.00	0.671
3	Silicon Oxide Potassium Aluminium Silicate + Biotite+ calcite		Si O_2+ K (Al Si_3 O_8)+ Ca	0.175
4	Silicon Oxide Potassium +Aluminium +Silicate Calcium Carbonate+ Montmorillonite		Si O_2+ K (Al Si_3 O_8)+ Ca (C O_3)+ Al4.00 +Si8.00 O24.00 +Ca1.00	0.064
5	Potassium+ Aluminium +Silicate Calcium +Magnesium +Silicate Silicon Oxide		K Al Si_3 O_8+ Ca Mg Si_2 O_6+ Si O_2	0.892
6	Quartz calcite + Iron Albite		Si6.00+ Ca (C O_3)+ Fe2.00+ Na (Al Si_3 O_8)	0.120
7	Quartz+ calcite + Manganese Silicate Biotite+ Calcite		Si6.00+ Ca Mn +2 Si_2 O_6+ Si5.28 Al3.68 Fe3.08 Mg1.40 Ti0.40 Na0.06 K1.92 Ca0.04 Ba0.04+ Ca	0.093
8	Silicon Oxide+ calcite + Montmorillonite+ Dolomite+ Biotite		Si O_2+ Ca (C O_3)+ Al4.00	0.158
9	Quartz+ calcite Sodium +Aluminium +Silicate		Si6.00+ Ca (C O_3)+ Na (Al Si_3 O_8)	0.057
10	Vermiculite+ Quartz+ Sodium Calcium Aluminium Silicate calcite +Carbonate		Mg12.00+(Ca , Na) (Al , Si)2 Si_2 O_8	0.153
11	Biotite+ Silicon Oxide+ Vermiculite+ Dolomite		Si5.71 Al2.74 K1.91 Ca0.06 Na0.03 Mg4.33 Cr0.10 Fe0.78 Mn0.04 Ti0.29+ Si O_2	0.196
12	Silicon Oxide+ Sodium +Aluminium Silicate Biotite+ Vermiculite		Si O_2+ Na (Al Si_3 O_8)+ Mg4.74 Fe0.96 Al2.86 Si5.44 O32.00 C24.00	0.226

XRF Analysis

XRF examinations aim to provide a comprehensive understanding of the regional pottery manufacturing techniques as well as the element concentrations present in the soil (Figure.6). The tests were performed using an ARL 8420 spectrometer. The UniQuant software was used to analyse the unknown samples. LOI was measured at 1050 °C with a one-hour ignition period, and no LOI corrections were applied. All 12 samples were studied through optical microscopy and the XRD method, with the results listed in Tables 4 and 5. The most frequent element identified was silica (SiO_2), which ranged from a maximum of 57.0% in Sample 12 to a minimum of 44.2% in Sample 02. Calcium (CaO) varied between 15.5% (Sample 05) and 10.3% (Sample 12).

Traced elements detected included Sulfur (SO_3), manganese (MnO), and chlorine (Cl). The presence of magnesium (MgO), manganese (MnO) and titanium (TiO_2) oxides indicates the unequivocal exploitation of the same raw material source. These elements were more probably related to the paints used for decorative purposes, as detailed in Tables 4-5.

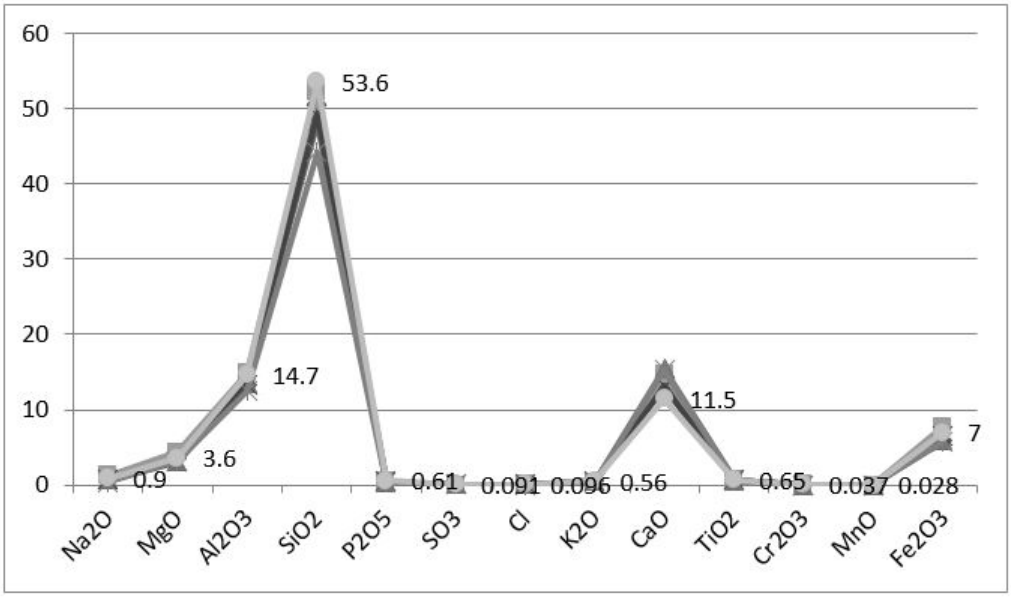


Figure. 6: *Proportions of the constituent elements of the ceramics based on XRF analysis,*

Table. 4: *Results of XRF analysis (wt%).*

(After: Conservation and Restoration Laboratory, Research Institute of Cultural Heritage and Tourism).

Sample%	1	2	3	4	5	6
Na_2O	0.90	0.43	0.82	0.71	1.3	0.68
MgO	3.6	3.2	3.2	3.1	4.4	3.5
Al_2O_3	14.7	12.5	13.4	13.6	14.9	13.3
SiO_2	53.6	44.2	49.3	48.2	52.2	50.6
P_2O_5	0.61	0.32	0.45	0.43	0.51	0.48
SO_3	0.091	0.11	0.049	0.074	ND	0.064
Cl	0.096	0.010	0.080	0.10	0.080	0.085
K_2O	0.56	0.42	0.54	0.52	0.31	0.52
CaO	11.5	15.4	13.1	15.5	14.8	14.1
TiO_2	0.65	0.53	0.65	0.56	0.66	0.61
Cr_2O_3	0.037	ND	0.011	0.011	0.049	0.016
MnO	0.028	0.019	0.030	0.022	0.030	0.028
FeO_3	7.0	5.8	6.5	5.9	7.8	6.0
LOI	6.46	16.86	11.63	11.07	2.65	9.65

Table. 5: *Results of XRF analysis (wt%).*

(After: Conservation and Restoration Laboratory, Research Institute of Cultural Heritage and Tourism).

Sample%	7	8	9	10	11	12
Na_2O	0.69	0.77	0.80	0.89	0.77	1.0
MgO	3.6	3.4	3.1	3.5	3.1	3.3
Al_2O_3	13.5	14.1	13.4	15.5	13.7	14.6
SiO_2	49.8	51.5	52.3	56.2	50.7	57.0
P_2O_5	0.52	0.37	0.50	0.49	0.44	0.42
SO_3	0.097	ND	0.020	ND	0.047	ND
Cl	0.093	0.085	0.075	0.11	0.10	0.12
K_2O	0.50	0.56	0.54	0.47	0.57	0.47
CaO	14.8	10.3	11.7	10.3	10.7	10.7
TiO_2	0.63	0.64	0.61	0.73	0.61	0.66
Cr_2O_3	ND	0.012	0.015	0.025	0.016	0.047
MnO	0.031	0.030	0.027	0.030	0.028	0.030
Fe_2O_3	6.6	7.1	6.0	7.7	6.9	7.1
LOI	8.81	11.03	10.69	3.83	11.97	4.33

Discussion

The results of archaeological excavations highlight the dominance and the long-run persistence of the Dalma culture at Gheshlagh. The site was therefore originally established by groups familiar with the culture. The local inhabitants also maintained contacts with Mesopotamia. Evidence of ties with the Ubaid culture is found in two pottery pieces that differ from other artefacts discovered at Gheshlagh. These include a vessel with a lenticular opening, a long neck, and a pouring opening (Sharifi and Motarjem 2018), as previously described. Notably, although architecture at Tepe Dalma and Kul Tepe is only sporadically documented (Hamlin 1975; Abedi 2014), Gheshlagh has yielded four distinct phases of stone and clay architecture from the Early Chalcolithic period (Sharifi and Motarjem 2018; Sharifi 2023). As no other site with a comparable thickness of the Dalma deposit has been excavated, Gheshlagh becomes all the more important. Additionally, the material culture, which includes obsidians, indicates that Gheshlagh not only served as a trade centre but also probably functioned as an intermediary point linking multiple regions (Mucheshi *et al.* 2023).

In this article, we embarked on a structural analysis of the Early Chalcolithic (Dalma) pottery sample from Tepe Gheshlagh. Regional geological studies indicate that the main part of the eastern Central Zagros with its northwest-southeast orientation, falls within the Sanandaj-Sirjan zone, the tectonic zoning of Iran (Berberian and King 1981). The region is covered with igneous rocks and sediments. The latter contains minerals such as calcite, quartz, manganese and metamorphic rocks (Sayyareh and Fonodi 2007:3). The attested phenocrysts are mainly of plagioclase type. Plagioclase serves as the main phase of the matrix, along with biotite and dolomite, which represent the secondary minerals (Rahim Zadeh *et al*. 2017:47). The same minerals present in the analysis of the regional pottery confirm the connection between the applied raw materials and their local sources.

In the conducted analyses, quartz was found to be the predominant element in the entire sample. Most specimens contained iron oxide, while 2 examples contained siltstone. It is evident that the calcite-containing pieces were subjected to kiln temperatures below 800 °C (Reedy 2008). The XRD analyses of the Gheshlagh pieces showed an iron content responsible for the red colour of the soil/fabric (see Miller 2017).

Conclusions

Results of investigations at Tepe Gheshlagh attest to occupations dating from 5500–5000 BCE. Research identified seven construction phases for the Chalcolithic contexts: four phases from the Dalma period, and three from the Late Chalcolithic (Godin VII) horizon. Notably, Gheshlagh is unique, as no other relevant site has produced a 9-metre-thick deposit, along with 4 construction phases, making it a key Dalma site in the central Zagros region.

The present work analysed an Early Chalcolithic (Dalma) pottery assemblage from a structural perspective. Chemical characteristics of the ceramic bodies were examined through petrography, XRF and XRD analyses to gain insights into the technological aspects of pottery manufacturing at Tepe Gheshlagh. Attempts were made to pinpoint the possible technological similarities and types of raw materials used. The XRF method was used to identify the elements present and to characterise the overall chemical composition, as well as the relative frequency of each element. The XRF analyses revealed that the major constituents of the Gheshlagh pottery matrix include silica (SiO_2), aluminium oxide (Al_20_3), and calcium (CaO). Additionally, magnesium oxide (MgO) and titanium oxide (TiO_2) were detected, consistent with the petrographic results.

In the XRD tests, the main phases were proved to be silicon oxide and calcium carbonate. Sodium aluminium, silicate, and quartz were also present in the entire sample.

The petrographic study characterised the Gheshlagh pottery in the following ways:

1. The texture was identified as silty or silty porphyry; 2. The temper was of organic type, with microscopic examinations revealing voids left by relevant vegetal materials; 3. The inclusions or fillers primarily consisted of quartz (both phenocryst and polycrystalline), calcite, iron oxide, sandstone, and siltstone; 4. Calcite occurred in both micrite and sparite forms, and was clarified as primary; 5. The existence of calcite in most specimens suggests that the firing temperature of the original vessels did not exceed 800–850 °C. However, single-coloured pastes (Samples 7, 11), which lacked carbonated, indicated possibly higher kiln temperatures; in these two samples, quartz was the main paste component. Given the reported presence of marl, sandstone, silica, and siltstone deposits in the region's geology- elements detected during the petrographic analyses- one may conclude that the pieces of the Dalma Painted Ware were locally sourced, with raw material obtained from regional sources. The petrographic, XRF and XRD analyses identified silica, calcite, quartz, plagioclase, iron, and clasts of metamorphic rocks, all of which are found in the regional soil.

Ultimately, regarding the research hypothesis about the native or imported nature of the ceramic objects, two Ubaid-type examples markedly differ from the rest of the samples in their origins and constituents. Specifically, they contained calcite in either micrite or sprite form and displayed a carbonate-rich clay matrix. Representing possible imports from uncertain regions, they attest to extra-regional interactions. The two pieces were made of a soil completely different from that of the Talvar basin. The Ubaid-type specimens consisted of a fine-grained light buff clay similar to Mesopotamian soils, which is not found in the Talvar region. In contrast, the red paste used in the Dalma Painted Ware examples aligns well with local soils characterised by a micaceous texture and red colour. This correlation suggests the idea that this pottery type is a local production, a fact also corroborated by petrography. Geological reports confirm the presence of quartz and calcite in the regional geology, making it reasonable to attribute a native provenance and localised production to all the pieces of the Dalma Painted Ware with red paste.

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