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Local Innovation and Craftsmanship: Technological Analysis (Petrography, XRD, XRF) of Late Chalcolithic Pottery from Tepe Ghabrestan, Qazvin Plain

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Abstract

From the perspective of pottery production during the Chalcolithic period at Tepe Ghabrestan (ca. 4200–3100 BCE), the Qazvin Plain constitutes one of the most important archaeological sites in the north central Iranian Plateau. This study was conducted with the aim of identifying the technology of pottery manufacture and the mineral compositions present in the ceramics. The research is significant for sourcing the provenance of Ghabrestan pottery and assessing the level of craftsmanship among its producers. The central research question concerns the quality of production and whether the pottery was locally made or imported. In this study, twenty pottery sherds from excavations at Tepe Ghabrestan selected from the ceramic repository of the Institute of Archaeology, University of Tehran were analyzed using physical tests (porosity measurement, water absorption, and density), petrography, X ray diffraction (XRD), and X ray fluorescence spectrometry (XRF), to perform elemental analysis and investigate the technological processes of pottery manufacture in the Qazvin Plain during the fourth millennium BCE. The results indicate the use of advanced and specialized production technology, reflecting the potters' skill in controlling the firing process and selecting high quality raw materials. Petrographic examination of thin sections confirmed the presence of minerals characteristic of the region, including quartz, biotite, calcite, and augite. A major finding was evidence of the use of high speed potter's wheels in producing Ghabrestan pottery, as shown by the uniform wall thickness and smooth surface finishes. Microscopic analysis confirmed the presence of inorganic tempers (mineral additives) incorporated to enhance mechanical properties and reduce cracking during firing. The clay used matches the geological composition of the Qazvin Plain, indicating local production of the pottery.

Keywords: Ghabrestan Tepe, Chalcolithic, Fourth Millennium BCE, Pottery Production Technology, Physical and Laboratory Analyses.

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Introduction

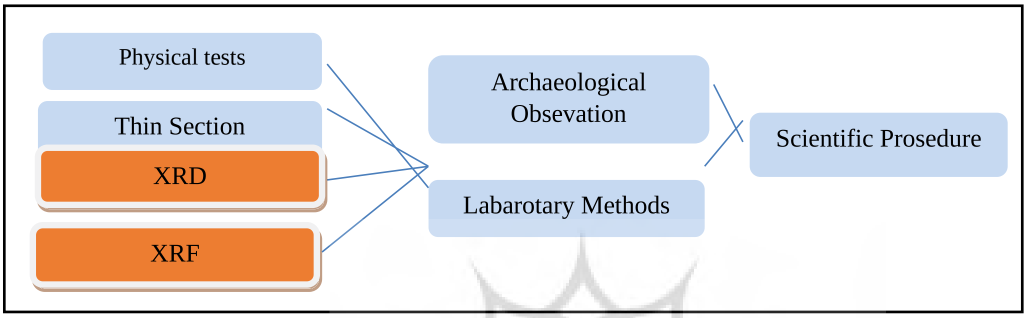
Technical and laboratory analysis of ceramic vessels constitutes one of the most precise and reliable methods for understanding and evaluating the development of ancient societies. The study of pottery is essential for determining the processes, quality of manufacture, and technological capabilities of past communities. Given the significance of the fourth millennium BCE, marked by the advent of metallurgy alongside the continued use and study of metal artifacts, research on ceramic finds is equally critical for reconstructing ancient societies in terms of production technology and provenance. Archaeological sites dating to this period in the north central region of Iran have been excavated, providing valuable data for such reconstructions (Yosefi *et al.,* 2018). Among these sites, Ghabrestan Tepe in the Qazvin Plain stands out as one of the most important excavated Chalcolithic sites in the north central Iranian Plateau, revealing the cultural sequence and continuity of the region between approximately 4200 and 3100 BCE (Talaei, 2013: 133; Schmidt & Fazeli, 2007: 2). One notable feature of this site is its occupation following the abandonment of Zagheh Tepe. From the mid fifth millennium BCE, between 4460 and 4240 BCE, Zagheh Tepe was abandoned, and Ghabrestan Tepe emerged as an industrial center specializing in metallurgy and pottery production (Fazeli Nashli, 2006: 35, 85).

From the perspective of pottery production during the Chalcolithic period at Tepe Ghabrestan (ca. 4200–3100 BCE), the Qazvin Plain is regarded as one of the most important and strategic archaeological sites in the north central Iranian Plateau. The core focus of this research is the identification of manufacturing technology, the mineral compositions present in the ceramics, the evaluation of clay workability by the potters, and the determination of whether the pottery recovered from this site was locally produced or imported. During the Late Chalcolithic period, human relations underwent significant transformations that ultimately led to the emergence of new social and political structures and to complex hierarchical societies resembling proto states, at least in certain regions of Iran. The pace of change accelerated both in terms of the material (technological) characteristics of societies and in their social, economic, and cultural structures (Matthews & Fazeli, 2022: 111, 127). It is evident that socio economic, political, and even religious changes have a direct connection with technological development, exerting profound influence on the lifestyles of prehistoric communities.

This study is essential for determining the provenance of pottery production at Tepe Ghabrestan during the fourth millennium BCE and for assessing the level of craftsmanship demonstrated by its producers. It is of particular importance in evaluating the extent of technological advancement in ceramic manufacturing and understanding the degree to which the studied community was aware of the technical capabilities involved in pottery production. Such investigations are vital for examining the progress of ancient societies and for tracing their trajectory toward industrialization.

Research Question and Hypothesis: The central question of this study is to determine the manufacturing technology, assess the quality of production, and establish whether the pottery of Tepe Ghabrestan in the Qazvin Plain during the fourth millennium BCE was locally produced or imported. Stratigraphy at the site has revealed four cultural phases of varying duration. Although the cultural sequence at Tepe Ghabrestan is broadly contemporaneous with Sialk Period III, notable differences emerge in terms of ceramic typology. Specifically, cultural continuity at Tepe Ghabrestan was disrupted twice; first with the emergence of Plum Ware (Ghabrestan I) and later with the appearance of Grey Ware (Ghabrestan III). By contrast, Phases II and IV are predominantly characterized by painted buff wares. In this study, twenty pottery sherds from Phase II of Tepe Ghabrestan were selected. This approach not only addresses the present research objectives but also establishes a methodological basis for future laboratory analyses of Plum Ware and Grey Ware, enabling a comparative evaluation of technological differences among these three distinct ceramic horizons. In the early part of the Late Chalcolithic, industrial and production oriented centers emerged across the Central Plateau of Iran. With its two hectare area, Tepe Ghabrestan appears to have been a major hub for pottery making and metallurgy, representing one of the most significant examples of such specialized centers (Asadi Ojaei *et al.*, 2019: 32).

Research Methodology: The clay used as raw material for pottery production possesses key properties of plasticity and workability. Clays are the result of the weathering of rocks, formed through erosion and deposition within the Earth's crust. Chemically, these rocks contain major groups of silicate minerals such as quartz, feldspar, pyroxene, and various micas of different sizes (Klien & Hurlbut, 1994: 564; Talaei, 2014). Thus, clay largely reflects the chemical composition of the parent rocks from which it is derived. Natural clays occur either in a relatively pure state or are mixed with other materials, and can be broadly classified into two main categories: primary clays and secondary clays. Primary clays, also known as residual clays, remain in the location where they formed as direct products of rock weathering. A notable property of primary clays is their exceptional softness, due to their particles being less than 3 microns in diameter. There are more than twenty identified types of primary clay, with varying mineral compositions that do not necessarily confer distinct physical properties (Goffer, 2007). Secondary clays, also called sedimentary clays, have been transported from their point of origin by natural agents such as flowing water, wind, or other forces. Along the way, they mix with other mineral particles and eventually settle in locations often far from their source. Secondary clays typically contain over 50% non clay materials such as sand, limestone, iron oxides, and organic matter (remains of plants and animals). Iron oxides in secondary clays often impart yellow, red, or brown coloration. The particles of secondary clay are generally smaller than those of primary clay, and this smaller size increases the plasticity and flexibility of the wet clay—making it more attractive to potters for manufacturing ceramic objects (Goffer, 2007: 235). The three principal properties that make clay suitable for pottery production are: plasticity (malleability when wet), hardness (upon drying), and strength and stability (after firing), (Talaei, 2014). Based on these considerations, the general procedures and methodological framework employed in this study are illustrated in Graph 1.



Graph 1: General workflow of the scientific study (Author, 2024).

Methodology

As illustrated in Figure 1, the research process was organized into two main phases: (1) archaeological description of inventoried pottery samples from Phase II of Tepe Ghabrestan (see: Appendix 1), and (2) laboratory analyses following physical testing of the specimens. The laboratory methods employed in this study fall into four categories:

1. Physical tests
2. Thin section petrographic analysis
3. XRF laboratory analysis
4. XRD laboratory analysis

In academic research, a correct and comprehensive description of any phenomenon significantly facilitates accurate interpretation. In the case of archaeological finds, such as pottery, initial observation followed by a thorough descriptive account can greatly enhance the understanding and contextualization of data. Archaeological observations of ceramics, as the first stage of study, provide essential information about the general and visible characteristics of the samples—such as color, texture, function, decoration (painted or plain). Hardness, softness, and durability indicate potential functional capacities, while color and surface finish may convey aesthetic appeal (Majidzadeh, 1991). Grey wares at Tepe Ghabrestan have been recovered from Phase II (Layer IX), Phase III (Layers VII and VIII), and Phase IV (Layer VI). These ceramics are coarse textured, incorporate chopped straw as temper, and are handmade. Incised geometric motifs form the sole decorative element. Excavation director Yusef Majidzadeh identified the grey wares at

Tepe Ghabrestan as the earliest of their type yet discovered in the Near East, stating that grey pottery was first produced in this region (Majidzadeh, 1977: 57). Laboratory studies represent an effective set of non descriptive analytical methods that allow archaeologists to go beyond visual and typological observations—such as color, motifs, and stylistic classification—and to acquire valuable technical data. These include identification of crystalline phases, determination of elemental composition, characterization of mineral constituents, and examination of fabric microstructures. By conducting such analyses, the study of pottery assemblages moves gradually beyond the basic descriptive and typological approaches typical in archaeology, toward an understanding of the more complex and fundamental aspects of prehistoric technologies.

Review of Literature

To date, numerous scholarly works, including articles, books, excavation reports, master's theses, and doctoral dissertations have been produced on excavations at Tepe Ghabrestan, particularly in relation to its pottery assemblages. Although the academic value of these sources varies from an archaeological perspective, the publications of the principal excavator of Tepe Ghabrestan, Yousef Majidzadeh, hold exceptional significance. Based on excavations conducted at Tepe Ghabrestan in the Qazvin Plain, four cultural periods comprising a total of nineteen occupational layers have been identified. The Plum Ware and Grey Ware assemblages examined in this study belong to Periods I and III of the site. Each type exhibits distinct ceramic attributes and styles; however, in terms of aesthetics, they rank relatively low and are primarily utilitarian in function (Majidzadeh, 1977: 35; Majidzadeh, 2008; 1981; 1976). In both Iranian and Mesopotamian archaeological literature, the abundance and diversity of ceramic artifacts have drawn particular scholarly attention to pottery finds, underscoring the importance of understanding production technologies rooted in ancient civilizations and cultures. Consequently, in order to achieve satisfactory results, it is necessary to complement conventional descriptive approaches to prehistoric ceramic assemblages with scientific techniques from related disciplines, thereby enabling an accurate reconstruction of pottery making techniques, such as those represented at Tepe Ghabrestan. Following the Islamic Revolution, research at Tepe Ghabrestan was continued under the direction of Hassan Fazeli Nashli with the objectives of establishing absolute chronology, identifying the characteristics of the fourth millennium BCE, and assessing the site's extent (Fazeli Nashli, 2006). In April 2004, Tepe Ghabrestan, covering six hectares, was subjected to geophysical survey aimed at locating Iron Age graveyards and industrial sectors of the fourth millennium BCE. This project was jointly conducted by the Iranian Cultural Heritage and Tourism Organization, the Institute of Archaeology at the University of Tehran, and the Department of Archaeological Sciences at the

University of Bradford. These investigations identified Iron Age agricultural canals, first millennium BCE burials, and industrial complexes dating to the fourth millennium at Ghabrestan (Fazeli & Schmidt, 2006: 32). Fazeli has argued that the technological changes observed in Ghabrestan pottery manufacture are embedded within the cultural sequence of north central Iran and, according to his hypothesis, represent gradual internal development. Moreover, stylistic and decorative diversity correlates with increasing socio political complexity (Fazeli *et al.,* 2005). In 2003 and 2004, the site was re examined, and excavations continued in 2006. These campaigns established the absolute chronology of occupation from the late fifth millennium through the late fourth millennium BCE (Fazeli & Abbasnejad, 2006). Multiple excavation seasons confirmed four cultural periods at Tepe Ghabrestan with relative dates spanning 5500–3000 BCE (Fazeli & Abbasnejad, 2006: 79–80). In 2001, Fazeli proposed a revised chronology dividing the site into: Early Chalcolithic (Ghabrestan I), ca. 4300–4200 BCE; Middle Chalcolithic (Ghabrestan II), ca. 4000–3700 BCE; and Late Chalcolithic (Ghabrestan III–IV), ca. 3700 BCE. He further concluded that permanent abandonment occurred at approximately 3200 BCE (Fazeli, 2004: 43). A substantial chronological gap in the cultural sequences of the Qazvin Plain, from ca. 3540 to 1780 BCE has been documented at key sites, including Tepe Ghabrestan and Sagzabad (Pollard, 2012: 14).

Archaeological Examination of Pottery Samples

The corpus analyzed in this study comprises 20 pottery specimens from Period II of the archaeological site of Tepe Ghabrestan, located in the Qazvin Plain. These samples, first excavated in 1973, were selected from the pottery archive of the Institute of Archaeology, University of Tehran. The first phase of the present research consisted of archaeological documentation of the specimens, including detailed recording of external features. Following a coding and labeling procedure, an identification sheet was prepared for each sample. In addition to photographic images, each sheet contained precise technical drawings of vessel forms and decorative motifs, thereby allowing closer scrutiny of the original vessel morphology and the painted or incised designs (Appendix 1). Recorded attributes included findspot, sherd type, color, temper, estimated firing temperature, presence or absence of decoration, and slip color/type. Among the samples, 4 are rim sherds and the rest are body sherds. Three rim fragments correspond to bowl forms, while one represents a jar type vessel. The predominant colors are dark buff and light buff; specimen GH.13 exhibits a buff hue with a reddish tint. All specimens bear a thin wash coating, and in approximately 85% of the cases, the slip color matches that of the body fabric (Nosrati, 2011). In terms of temper, the majority of samples contain non organic inclusions; however, specimen GH.17 uniquely combines both non organic and organic temper (see: Fig. 1: A). All samples were wheel made, with appropriate firing quality, and appear to have been produced using a fast wheel. Overall, the assemblage can be classified as fine ware ceramics. In specimens GH.11, GH.17, and GH.18, the core fabric exhibits two distinct colors (see: Fig. 1: B, C, D). This bicolored core likely results from short firing durations or insufficient exposure to peak kiln temperature. Evidence suggests that Ghabrestan potters had not yet achieved full control over firing temperature and kiln conditions; in some cases, abbreviated firing cycles and the inability to sustain maximum heat led to partial color variation within vessel bodies. Nonetheless, all specimens display complete firing.

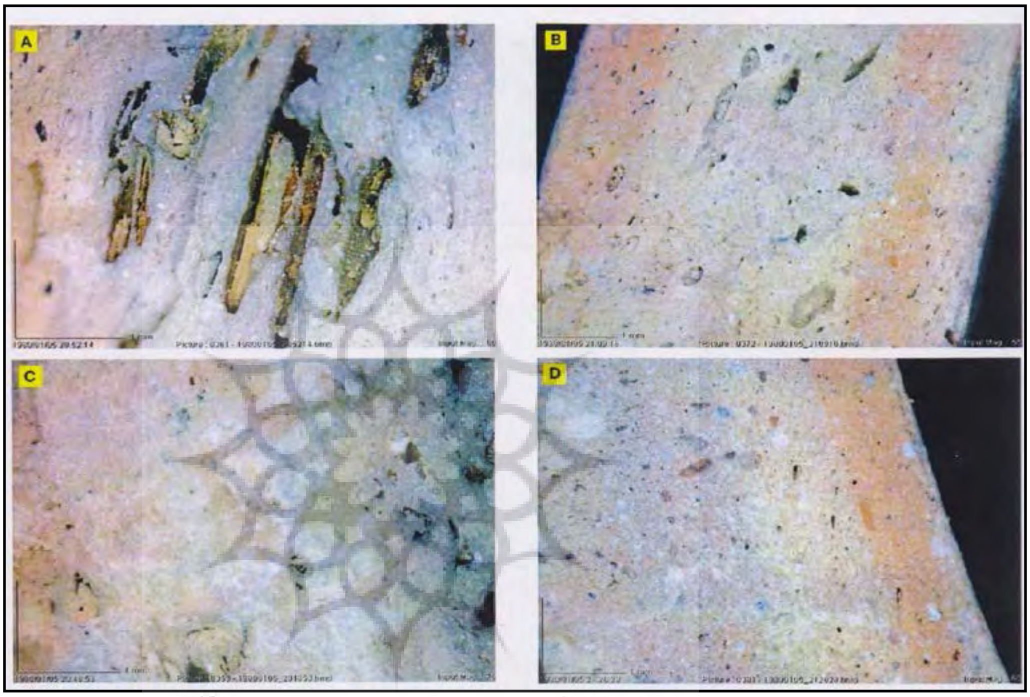


Fig. 1 A: Use of both non organic and organic tempers in specimen GH.17; B, C, D: Bicolored core fabrics observed in specimens GH.11, GH.17, and GH.18. (Author, 2024).

Description and Results of Physical Properties Analysis

In this stage of the study, physical parameters such as porosity, water absorption, void volume, and density of the samples were evaluated. The porosity of ceramic specimens largely reflects the nature of the raw materials used in pottery production and the degree of vitrification achieved during firing. Under fired objects tend to have higher porosity, whereas well fired specimens exhibit lower porosity. The procedure began with measurement protocols for void volume, percentage water absorption, percentage porosity, and apparent and true densities. To measure sample volume, specimens were first placed in an electric oven at 100 °C for 24 hours to ensure complete drying. Each dried sample was then weighed with precision, and its dry weight was recorded as M1. Subsequently, the specimens were immersed in distilled water for 48 hours to achieve full saturation. The saturated weight in the immersed state (M2) was measured. Each specimen was then removed from the water, its surface rapidly dried with a cloth, and the saturated weight out of water (M3) recorded. Using these measurements, we calculated the apparent volume (Va), real volume (Vr), and void volume (Vp) of each specimen according to the following formulas:

- Void volume (Va) = M3 – M2
- Real volume (Vr) = M1 – M2
- Porosity volume (Vp) = M3 – M1

From these values, both porosity and water absorption capacity, apparent and actual, were determined. Porosity represents the ratio of the total void space in the object to its overall volume and depends on factors such as grain size distribution, compaction, pore structure, and firing temperature. Conventionally, porosity is expressed as a percentage, calculated using the standard formula for apparent porosity percentage.

$$\frac{M3 - M1}{\mathrm{M3 - M2}} \times 100$$

Water absorption capacity is defined as the ratio of the mass of water absorbed by a dry object until saturation to the object's initial dry mass. This property relates to porosity, grain dimensions, particle morphology, and ambient moisture. In this study, water absorption capacity was expressed as a percentage.

$$\frac{M3 - M2}{\mathrm{M1}} \times 100$$

Density (specific gravity) measures the mass per unit volume of a material. Apparent density, calculated as the mass divided by the apparent volume is expressed in g/cm³ using the conventional formula, while true density (representing mass per real volume, or impermeable volume) was likewise computed in g/cm³ according to standard procedures.

$$Pr = \frac{M1}{\mathrm{M1 - M2}} \ (\mathrm{g/cm^3})$$

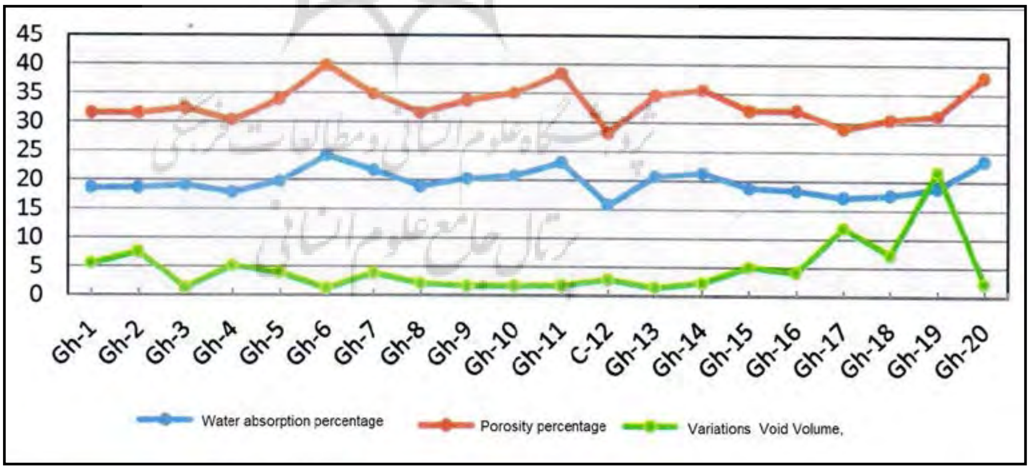
Analysis of Physical Properties Results

As shown in Table 1 and Figure 1, the percentages of porosity and water absorption among the samples are heterogeneous. For specimens GH.17, GH.18, and GH.19, there is a sudden increase in void volume. However, the porosity and water absorption percentages of these three samples do not differ significantly from those of the other specimens. This may be explained by the considerably larger size and volume of these samples compared to the rest, thereby yielding higher absolute void volumes.

Nonetheless, because porosity and water absorption capacity are expressed as percentages, the increase in specimen size has little effect on their values.

Table 1: Mean and Range of Void Volume, Porosity, and Water Absorption for the Samples (Author, 2024).

Sample Count	**Range of Void Volume**	**Mean of Void Volume**
Total number of samples: 20	Recorded range of void volume: 1.151 cm³ < GH < 21.561 cm³	Mean void volume: 4.661 cm³
Minimum void volume: specimen 6 at 1.151 cm³		
Maximum void volume: specimen 19 at 21.561 cm³		
Sample Count	**Range of Porosity Percentage**	**Mean of Porosity Percentage**
Total number of samples: 20	Recorded range of porosity percentage: 28.076 % < GH < 39.370 %	Mean porosity percentage: 33.150 %
Minimum porosity: specimen 12 at 28.076 %		
Maximum porosity: specimen 6 at 39.370 %		
Sample Count	**Range of Water Absorption Percentage**	**Mean of Water Absorption Percentag**
Total number of samples: 20	Recorded range of water absorption percentage: 15.790 % < GH < 24.140 %	Mean water absorption percentage: 19.703 %
Minimum water absorption: specimen 12 at 15.790 %		
Maximum water absorption: specimen 6 at 24.140 %		



Graph. 2: Variations in Void Volume, Porosity, and Water Absorption among the Samples (Author, 2024).

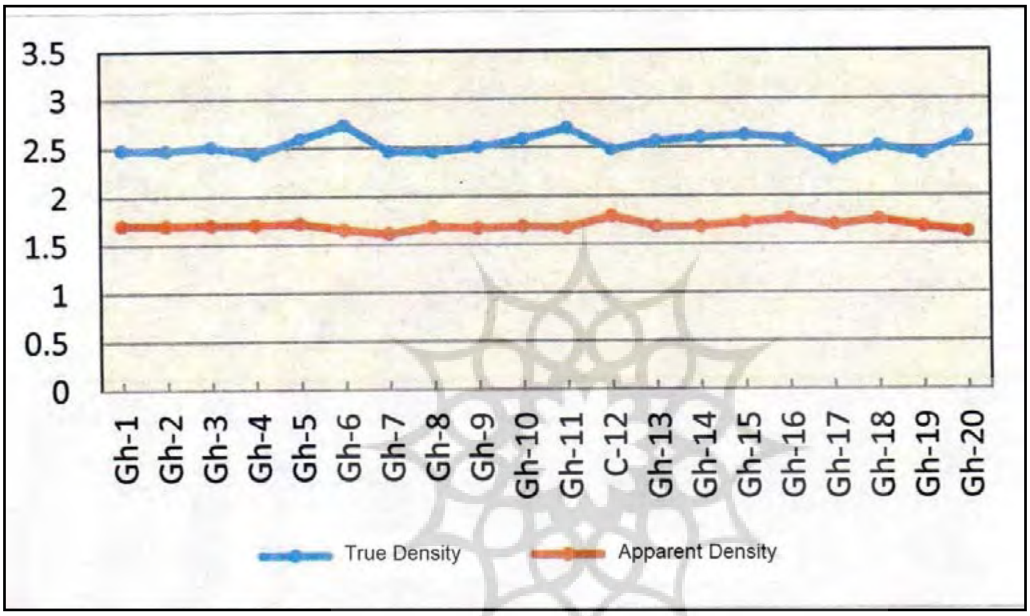
Results of Thin Section Analysis

Another analytical method employed in this research, albeit on a limited scale was the preparation and examination of a thin section from one specimen out of the total twenty analyzed. Thin section study is a technique in which rock and mineral slices are observed under an optical microscope. This method is the most common procedure in

Table 2. Range and Mean of Apparent and True Density of the Samples (Author, 2024).

Sample Size	Range of apparent density variation	Mean apparent density
20 specimens	1/601 < GH < 1/778	1/1685
Lowest apparent density = Sample 7 with an apparent density of 1.601		
The highest apparent density = sample 12 with an apparent density of 1.778.		

Sample Size	Range of true density	Mean true density
20 specimens	2/127 < GH < 2/730	2/529
The lowest real density = sample 4 with a real density of 2.127.		
The highest true density = sample 17 with a true density of 2.730.		



Graph. 3: Variations in Apparent and True Density among the Samples (Author, 2024).

geological studies, where it is used for classification, provenance investigation, and the examination of secondary alterations within rocks. Since the 1940s, thin section analysis has also been applied in archaeology for the purposes of provenance determination and identifying pottery manufacturing techniques. In ceramic studies using this method, a thin section must first be prepared from the sample. Preparation involves cutting a narrow slice of pottery, usually vertically to the vessel's surface from a polished sherd, and adhering the polished surface with resin to a glass slide. The mounted piece is then further polished until it reaches a thickness of approximately 0.03 mm. At this thickness, under polarized light, the constituent minerals reveal distinctive optical properties, thereby enabling mineral identification (Riederer, 2004: 145). In continuation of this segment of the study, the results of the thin section examination are presented. The thin section of specimen GH.17, illustrated in Figure 2, shows an extremely high porosity in the fabric (Nosrati, 2011).

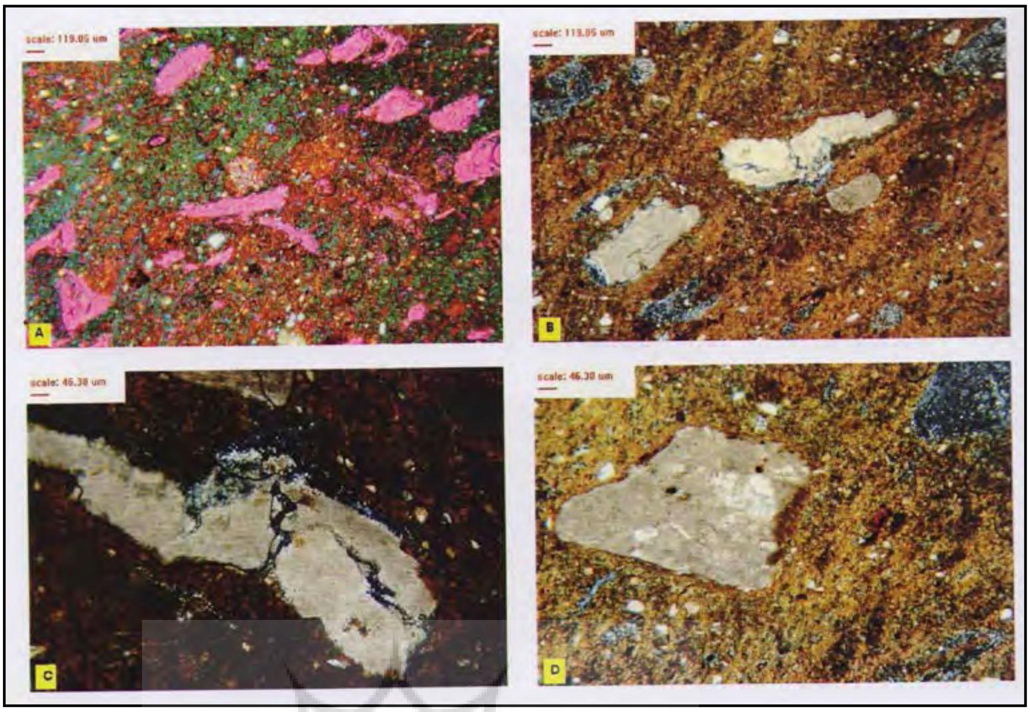


Fig. 2: Thin Section of the Pottery Specimen from Tepe Ghabrestan (Author, 2024).

Petrographic Observations

The clay used in manufacturing the specimen was of poor quality and had not been sufficiently kneaded. The quantity of quartz and biotite (black mica) serving as filler material in the fabric is very low. The added temper predominantly consists of calcite and, probably, a small amount of straw (Fig. 2: B). Straw traces appear as void spaces in the matrix. The calcite grains remain entirely intact and unhydrated within the fabric (Fig. 2: C). It appears that the calcite particles, enveloped in thick, veined coatings, indicate that the burial environment was moist or that the sherd experienced excessive water absorption (Fig. 2: D). On this basis, it is not possible to precisely estimate the specimen's firing temperature; however, it can be asserted that the firing temperature did not reach 900 °C. The Central Iranian mountain ranges, which encircle the southern sector of the Qazvin Plain, are largely composed of tuffs and igneous rocks dating to the Tertiary period. The lithological diversity of the area reveals specific minerals and raw materials that are highly likely to be present in the pottery of Tepe Ghabrestan. Thus, the presence of minerals such as biotite (black mica), calcite, and quartz, as observed in the thin sectioned samples from Tepe Ghabrestan, is entirely consistent with the geological context. Overall, it may be concluded that the source clay used in the manufacture of Tepe Ghabrestan pottery is compatible with soils native to the Qazvin Plain (Fazeli *et al.*, 2002; Emami, 2008).

Results of X Ray Diffraction (XRD) Analysis

X ray diffraction (XRD) can provide archaeologists with valuable information regarding the identification of mineral phases in ceramic artifacts, whether these minerals were originally present in the raw material or formed or altered due to factors such as firing conditions, temperature, or kiln atmosphere. In brief, for XRD analysis each sample is first ground into an extremely fine powder and then exposed to monochromatic X ray beams with wavelengths ranging from 1.00 to 1.01 Å. The result is a characteristic diffraction pattern. Every crystalline material produces a unique diffraction pattern, which can be identified by comparison with standard reference patterns. Depending on the nature of the sample, the required amount for each analysis ranges from 0.5 g to 3 g, and the final result is qualitative (Talaei *et al.,* 2009).

From among the twenty analyzed specimens, samples GH.2, GH.9, GH.17, GH.18, and GH.19 were selected for XRD testing. Quartz, albite, and augite were identified as the principal phases in these samples. Hematite appeared as a secondary phase and was found in nearly all specimens. In GH.17, where hematite is absent, montmorillonite was detected as a secondary phase, while calcite was identified as a neoformation phase. The presence of iron oxides such as hematite in clay—except in pure clays such as kaolinite is common. Hematite plays a significant role in determining pottery color, an effect influenced by the calcite (lime) content of the clay and attainable only at high firing temperatures if the clay is low in lime. The XRD spectra also yield insights into firing processes. Not all phases detected by XRD originate in the raw clay; some are secondary phases formed from the decomposition of clay minerals during firing. In these specimens, the primary phases include quartz, augite, illite, and in some cases calcite, whereas the remaining phases are secondary. The presence of particular phases can indicate minimum and maximum firing temperatures. Quartz occurs as a common phase in all samples. Albite is present in nearly all specimens, indicating firing temperatures did not exceed 850–900 °C, since mullite formation requires temperatures above approximately 950 °C, a level rarely reached in these ceramics, given the technological constraints of the period. The presence of hematite in certain samples suggests that the clay was low in lime and that firing temperatures were around 850 °C. The absence of phases such as glenite, diopside, and anorthite further supports the conclusion that the clay was low in lime and that firing temperatures remained below 1000 °C. Notably, the occurrence of augite in most specimens is significant, as this phase typically forms above 1000 °C. Given the concurrent presence of albite (indicative of temperatures below 1000 °C), the augite in these wares must have been inherited from the raw clay rather than formed during firing. This is consistent with the geological setting, where local clays derive from the weathering of volcanic rocks. As indicated by Tables 3 and 4, all elements present in the Tepe Ghabrestan specimens are likewise found in local soils. This demonstrates that the pottery of Tepe Ghabrestan was produced using clay sourced from the surrounding Qazvin Plain (Nosrati, 2011).

Table 3: Major Elements (Weight Percent) in Pottery Samples from Tepe Ghabrestan (Author, 2024).

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	TiO_2	MnO	P_2O_5	SO_3	L.O.I
	%	%	%	%	%	%	%	%	%	%	%	%
Gh-2	56.89	14.65	7.56	9.39	1.30	3.07	2.96	0.667	0.152	0.240	0.045	2.89
Gh-9	56.64	14.44	7.08	10.95	1.40	2.69	2.97	0.666	0.138	0.182	0.068	2.40
Gh-17	55.14	11.61	6.76	7.00	0.47	3.72	6.80	0.630	0.077	0.545	0.195	6.75
Gh-18	59.16	14.05	7.23	9.42	1.18	2.89	2.76	0.623	0.148	0.254	0.043	1.90
Gh-19	60.68	13.16	7.56	8.71	1.08	2.95	2.51	0.639	0.144	0.224	0.023	2.05

Table 4: Trace Elements (ppm) in Pottery Samples from Tepe Ghabrestan (Author, 2024).

Sample	Cl	Ba	Sr	Cu	Zn	Pb	Ni	Cr	V	Ce	La	Mo	Nb	Ga	Zr	Y	Rb
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Gh-2	231	451	366	187	112	38	82	87	111	29	14	3	8	15	163	32	56
Gh-9	204	493	441	74	98	28	91	56	111	81	43	19	12	15	177	32	58
Gh-17	254	298	288	67	136	17	88	104	125	26	12	5	9	14	159	40	63
Gh-18	242	591	384	145	107	34	77	81	117	60	31	6	21	15	160	39	66
Gh-19	188	485	464	67	115	26	74	60	114	23	12	26	19	16	169	35	73

Therefore, it can be concluded that the chemical composition of the mineral constituents identified in the Tepe Ghabrestan samples is, to a considerable extent, determined not only by mineral transformations occurring during the firing process but also by the geological characteristics and raw material composition of the Qazvin Plain. In clearer terms, the pottery of Tepe Ghabrestan was manufactured using clay sourced from the Qazvin Plain. Finally, based on the results of the XRD analysis, the firing temperature of the specimens is estimated to have been within the range of approximately 900–970 °C.

Results of X Ray Fluorescence (XRF) Analysis

This method is employed for elemental analysis in a semi quantitative manner. When the radiation generated in the X ray tube of the XRF instrument strikes the atoms constituting the sample, it produces fluorescence X rays. In this process, primary radiation dislodges electrons from various atomic shells, leaving the atom in an excited and unstable state. To compensate for the loss, an electron from a higher energy shell moves down to a lower energy shell. During these atomic transitions, the excess energy released is emitted as X ray photons of specific wavelengths, these are fluorescence X rays. Measuring the wavelength identifies the corresponding element, and measuring the intensity reveals the abundance of that element in the sample. Samples for XRF analysis may be prepared in powder, sheet, or layer form. The XRF instrument can identify all elements with an atomic number of 11 or higher and is conventionally used alongside mineralogical techniques such as XRD and thin section petrography as complementary methods (Hadian Dehkordi, 2007: 75–76). The specimens selected for XRF analysis were the same five samples tested by XRD. Measurements were performed by the Konsaran Binalud Company using a Philips PW1480 model instrument. Results are presented as major elements (in weight percent) and trace elements (in parts per million, ppm), (Nosrati, 2011).

XRF Results for Pottery Samples from Tepe Ghabrestan, Qazvin Plain

According to XRF data, the most abundant oxides are silica (SiO_2) and alumina (Al_2O_3). Following these, calcium oxide (CaO) and ferric oxide (Fe_2O_3) dominate among the major constituents. The Tepe Ghabrestan specimens have a mean loss on ignition (L.O.I.) value of 3.198 %. Review of Tables 3 and 4 (major and trace elements) indicates that all elements detected in the samples also occur in local soils. This finding confirms that Ghabrestan pottery was produced using clay from the Qazvin Plain. The XRF results identify the following major elements: Si, Al, Ca, Fe, Na, K, and Mg; minor elements include Ti, Mn, P, and S. Seventeen trace elements, measured in ppm, were also detected. Variability in chemical composition is much greater among trace elements than in the major element group. Consequently, the samples cannot be distinguished into separate chemical groups based on their composition (Nosrati, 2011).

Conclusions

The combined results from physical property testing, thin section petrography, and XRD/XRF analyses of twenty Period II pottery samples from Tepe Ghabrestan in the Qazvin Plain, dating stratigraphically to the fourth millennium BCE, indicate a highly developed ceramic industry in north central Iran. The specialization of production during the transitional Chalcolithic period, along with the reorganization of ceramic manufacture, reflects rising cultural complexity and socio economic development in this era (Matthews & Fazeli, 2022: 122). Given the cultural homogeneity documented in north central Iran during the fourth millennium BCE, similar studies allow these findings to be generalized region wide. Archaeological evidence of this cultural homogeneity has also been observed at excavated sites such as Sialk III (Kashan), Tepe Hissar I (Damghan), Tepe Ozbeki (Karaj), and Tepe Arisman (Natanz). From a stylistic standpoint, the fourth millennium pottery of north central Iran, referred to as the “Sialk III Ceramic Horizon” (Talaei, 2013), displays a wide range of buff shades, including light buff, dark buff, and buff tinged with red. Ceramic production in this horizon reached a high point of refinement and beauty. Technological advances included the emergence of the potter's wheel, the use of non organic tempers, thorough wedging of clay, the improvement of pottery kilns (Majidzadeh, 1977), and mastery over increasing and maintaining kiln temperature. It appears that by the fourth millennium BCE a kiln type had developed in which the firebox was located beneath the chamber holding the vessels, separated by a flue or opening. This design facilitated control of the kiln atmosphere necessary for producing cream and buff wares. Thus, kilns in this period had become more advanced, although their specific structural features have yet to be fully investigated. Laboratory results reveal, however, that potters had not yet achieved complete mastery in controlling temperature and atmosphere: several tested specimens exhibit bicolored cores, likely due to short firing duration or insufficient time at peak temperature, while others display greenish hues from excessive firing, especially among painted wares. Nonetheless, the firings were complete, and all specimens demonstrate high mechanical strength. Heat plays a decisive role in pottery strength; the higher and more controlled the firing temperature, the greater the vessel's resistance to mechanical pressure and fracture. Mineralogically, the principal constituents of the sample fabrics are quartz, augite, orthoclase, plagioclase, albite, and biotite, with some variation in proportions among samples. The quartz is angular, reflecting derivation from igneous or metamorphic rocks of the Qazvin Plain. The occurrence of plagioclase, orthoclase, biotite, and augite further supports an igneous or metamorphic source for the raw clay. Examination of phases formed during firing yields an estimated firing temperature range of 900–970 °C. On this basis, it can be confidently stated that the pottery was made using local Qazvin Plain clay. Moreover, the discovery of a pottery firing kiln at Tepe Ghabrestan strongly indicates that production took place on site rather than in an external location.

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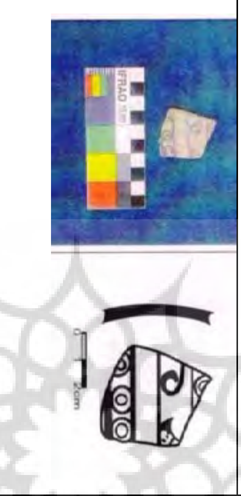
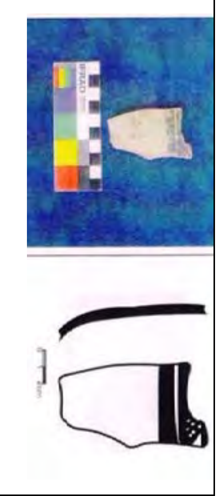
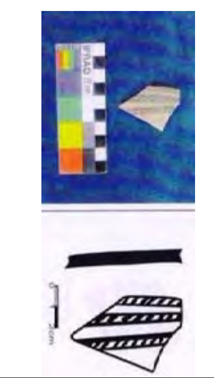
Conflict of Interest

In adherence to ethical publication standards, the authors affirm that there are no conflicts of interest, either personal or financial, that could have influenced the content or conclusions presented in this research.

Appendix 1. Catalogue of selected pottery from Period II of Tepe Qabrestan (Author, 2024).

Code	Gh1	Gh2	Gh3	Gh4	Gh5	Gh6	Gh7	Gh8	Gh9	Gh10
sherd type	body	body	body	rim	body	body	rim	body	body	body
color	dark buff	dark buff	light buff	dark buff	light buff	light buff	dark buff	light buff	light buff	light buff
temper	non organic	non organic	non organic	non organic	non organic	non organic	non organic	non organic	non organic	non organic
method making	wheel made	wheel made	wheel made	wheel made	wheel made	wheel made	wheel made	wheel made	wheel made	wheel made
firing temperature	complete firing	complete firing	complete firing	complete firing	complete firing	complete firing	complete firing	complete firing	complete firing	complete firing
decoration	painted	painted	painted	painted	painted	painted	painted	painted	painted	painted
slip type.	thin wash	thin wash	thin wash	thin wash	thin wash	thin wash	thin wash	thin wash	thin wash	thin wash
slip color	dark buff	dark buff	light buff	dark buff	light buff	light buff	dark buff	light buff	light buff	light buff
										

Code	Gh11
sherd type	body
color	light buff
temper	non organic
method making	wheel made
firing temperature	complete firing
decoration	painted
slip type.	thin wash
slip color	Pea color with white undertones

Code	Gh16
sherd type	body
color	dark buff
temper	non organic
method making	wheel made
firing temperature	complete firing
decoration	painted
slip type.	thin wash
slip color	light buff

Code	Gh12
sherd type	body
color	dark buff
temper	non organic
method making	wheel made
firing temperature	complete firing
decoration	painted
slip type.	thin wash
slip color	light buff

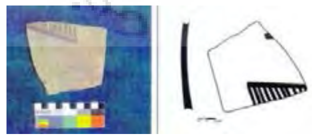
Code	Gh17
sherd type	rim
color	dark buff
temper	Organic&non organic
method making	wheel made
firing temperature	complete firing
decoration	plain
slip type.	thin wash
slip color	dark buff

Code	Gh13
sherd type	body
color	Pea color with reddish undertones
temper	non organic
method making	wheel made
firing temperature	complete firing
decoration	painted
slip type.	thin wash
slip color	Pea color with reddish undertones

Code	Gh18
sherd type	body
color	dark buff
temper	non organic
method making	wheel made
firing temperature	complete firing
decoration	painted
slip type.	thin wash
slip color	dark buff

Code	Gh14
sherd type	body
color	dark buff
temper	non organic
method making	wheel made
firing temperature	complete firing
decoration	painted
slip type.	thin wash
slip color	dark buff

Code	Gh19
sherd type	body
color	dark buff
temper	non organic
method making	wheel made
firing temperature	complete firing
decoration	painted
slip type.	thin wash
slip color	dark buff



Code	Gh15
sherd type	rim
color	dark buff
temper	non organic
method making	wheel made
firing temperature	complete firing
decoration	painted
slip type.	thin wash
slip color	dark buff

Code	Gh20
sherd type	body
color	light buff
temper	non organic
method making	wheel made
firing temperature	complete firing
decoration	painted
slip type.	thin wash
slip color	light buff

References

- Asadi Ojaei, S. K., Abbasnejad, R., Fazeli Nashli, H. & Valipour, H. R., (2019). "Analysis Socio-Economic Complexitiesof the Societies of the Central Plateau of Iran During 5th Millennium B.C.E. on the Basis of Pottery Technology". *Archaeological Research of Iran,* 9(20), 21-36. https://doi.org/10.22084/nbsh.2019.16225.1739

- Emami, S. M. A., Volkmar, J. & Trettin, R., (2008). "Quantitative characterisation of damage mechanisms in ancient ceramics by quantitative X-ray powder diffraction, polarisation microscopy, confocal laser scanning microscopy and non-contact mode atomic force microscopy". *Surface Engineering,* 24(2), 129–137. https://doi.org/10.1179/174329408X298157

- Fazeli Nashli, H., (2004). "Relative and absolute chronology of Tepe Ghabrestan, Qazvin Plain". *Archaeological Reports,* 3: 37–50.

- Fazeli Nashli, H., (2006a). "Archaeological investigations in the Qazvin Plain in 2003". In: *Archaeology of the Qazvin Plain* (pp. 211–273). Tehran: University of Tehran Press.

- Fazeli Nashli, H., (2006b). *Political and social changes in the Qazvin Plain: Excavations at Tepe Ghabrestan, season III.* Tehran: Archaeological Research Center, Iranian Cultural Heritage, Handicrafts and Tourism Organization.

- Fazeli Nashli, H. & Schmidt, A., (2006). "Tepe Ghabrestan: Geophysical survey report". *The International Journal of Humanities,* 13(3), 31–50. https://dor.isc.ac/dor/20.1001.1.25382640.2006.13.3.5.7

- Fazeli, H. & Jamali, M., (2002, November 8–9). "Explaining the process of specialized pottery production in the prehistoric village of Zagheh, based on archaeological studies and petrography results". In: *Proceedings of the First Symposium on Archaeometry in Iran: The Role of Basic Sciences in Archaeology* (pp. xx–xx). Tehran: Archaeological Research Center, Iranian Cultural Heritage Organization.

- Fazeli, H., Wong, E. H. & Potts, D. T., (2005). "The Qazvin Plain revisited: A reappraisal of the chronology of northwestern Central Plateau, Iran, in the 6th to the 4th millennium BC". *Ancient Near Eastern Studies,* 42(3): xx–xx. https://doi.org/10.2143/ANES.42.0.2004448

- Goffer, Z. (2007). Archaeological chemistry. John Wiley & Sons. https://doi.org/10.1002/0471915254

- Hadian Dehkordi, M., (2007). "Application of laboratory research in the conservation and restoration of historic buildings (materials and structures)".

Tehran: Conservation and Restoration Research Institute, University of Tehran.

- Klein, C. & Hurlbut, C. S., Jr., (1993). *Manual of mineralogy* (21st ed.). New York, NY: John Wiley & Sons.

- Majidzadeh, Y., (1976). *The early prehistoric cultures of the Central Plateau of Iran: An archaeological history of its development during the fifth and fourth millennia BC* (Doctoral dissertation). University of Chicago.

- Majidzadeh, Y., (1977). "Excavations at Tepe Ghabrestan, Sagzabad". *Marlik,* 2: 53–71.

- Majidzadeh, Y., (1981). "Sialk III and the pottery sequence at Tepe Ghabrestan: The coherence of the cultures of the Central Iranian Plateau". *Iran,* 19(1): 141–146. https://doi.org/10.2307/4299711

- Majidzadeh, Y., (1991). "Archaeology and pottery". *Archaeology and History,* 5(2): 4–14.

- Matthews, R. & Fazeli Nashli, H., (2022). *The archaeology of Iran from the Palaeolithic to the Achaemenid Empire.* Routledge. https://doi.org/10.4324/9781003224129

- Nosrati, S., (2011). *Study of fourth millennium BCE pottery technology using XRD and XRF laboratory methods in north central Iran (Case study: Sialk III, Arisman I, and Ghabrestan II pottery)*, (Master's thesis). University of Isfahan, Faculty of Conservation.

- Pollard, A. M., Davoudi, H., Mostafapour, I., Valipour, H. R. & Fazeli Nashli, H., (2012). "A new radiocarbon chronology for the late Neolithic to Iron Age in the Qazvin Plain, Iran". *The International Journal of Humanities,* 19(3): 110–151. https://dor.isc.ac/dor/20.1001.1.25382640.2012.19.3.3.7

- Riederer, J., (2004). "Thin section microscopy applied to the study of archaeological ceramics". *Hyperfine Interactions,* 154(1–4): 143–158. https://doi.org/10.1023/B:HYPE.0000032029.24557.b1

- Schmidt, A. & Fazeli, H., (2007). "Tepe Ghabrestan: A Chalcolithic tell buried in alluvium". *Archaeological Prospection,* 14(1): 38–46. https://doi.org/10.1002/arp.291

- Talaei, H., (2013). *Prehistory of Iran: The Chalcolithic Age.* Tehran: SAMT.

- Talaei, H., (2014). *Eight thousand years of pottery in Iran.* Tehran: SAMT.

- Talaei, H., Aliyari, A. & Zoghi, Y., (2009). "Study of fifth millennium BCE pottery technology using XRD and XRF laboratory methods in north central Iran". *Archaeological Studies,* 1: 65–84. https://jarcs.ut.ac.ir/article_28631.html?lang=en

- Yosefi, R., Zeighmi, M. & Baghizadeh, S., (2018). “Classification and Typology of Late Chalcolithic Period’s Pottery Culture of Northern Central of Iran’s Plateau in light of Northern Mound’s Findings of MeymanatAbad Tepe”. *Journal of Archaeological Studies,* 10(1): 227-246. https://doi.org/10.22059/jarcs.2018.219039.142346

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مطالعۀ فن‌آوری تولید سفال‌های تپه قبرستان در دورۀ مس‌وسنگ (حدود ۳۱۰۰-۴۲۰۰ پ.م.) با استفاده از روش‌های مطالعات فیزیکی و آزمایشگاهی (پتروگرافی FRX-DRX)

احمد علی‌یاری[I]

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چکیده

از منظر تولید سفال در دورۀ مس‌وسنگ تپه قبرستان حدود (۴۲۰۰ تا ۳۱۰۰ پ.م.)، دشت قزوین یکی از مهم‌ترین محوطه در شمال‌مرکزی فلات ایران محسوب می‌شود. با هدف شناخت فناوری تولید و ترکیبات کانی‌های موجود در سفال‌ها این پژوهش انجام شد. پژوهش حاضر برای منشأیابی تولید سفال تپه قبرستان و میزان مهارت تولیدکنندگان ضروری و اهمیت دارد. پرسش اساسی و اصلی این پژوهش، بررسی میزان کیفیت تولید و بومی یا وارداتی بودن سفال‌ها است. در این پژوهش ۲۰ نمونۀ قطعه سفال از کاوش تپه قبرستان که از بانک سفال مؤسسه باستان‌شناسی دانشگاه تهران انتخاب گردیدند با استفاده از آزمایش‌های فیزیکی (سنجش تخلخل، جذب آب و دانسیته)، پتروگرافی، پراش پرتو ایکس (XRD)، طیف‌سنجی فلورسانس پرتو ایکس (XRF)، مورد بررسی قرار گرفته است، برای تجزیه عنصری و شناخت فن‌آوری ساخت سفال در طول هزارۀ چهارم پیش‌ازمیلاد در منطقه مورد آزمایش قرار گرفت. نتیجۀ مطالعۀ نمونه‌ها نشان می‌دهد در ساخت سفال از فن‌آوری پیشرفته و تخصصی استفاده شده است؛ نشان‌دهندۀ مهارت سفالگران در کنترل فرآیند پخت و استفاده از مواد اولیه مرغوب است. مطالعات پتروگرافی برروی مقاطع نازک سفال‌ها وجود کانی‌های مشخصۀ منطقه، ازجمله کوارتز، بیوتیت، کلسیت و اوژیت را تأیید کرد. یکی از یافته‌های مهم این پژوهش، شناسایی فناوری پیشرفتۀ چرخ سفالگری در تولید سفال‌های تپه قبرستان بود. ضخامت یکنواخت دیواره‌ها و کیفیت سطح نمونه‌ها به‌وضوح نشان می‌دهد که از چرخ سفالگری تند استفاده می‌شده است؛ همچنین، مطالعات میکروسکوپی وجود آمیزه‌های غیرآلی (مواد افزودنی معدنی) را در بافت سفال‌ها تأیید کرد که به‌منظور بهبود خواص مکانیکی و کاهش ترک‌خوردگی در هنگام پخت به‌کار می‌رفته‌اند. خاک مورداستفاده برای ساخت سفال، با ترکیبات منطقۀ دشت قزوین تطابق دارد، که نشان‌دهندۀ تولید بومی سفال است.

کلیدواژگان: تپه قبرستان، مس‌وسنگ، هزارۀ چهارم، فن‌آوری تولید سفال، مطالعات فیزیکی و آزمایشگاهی.

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