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ARCHAEOMETRIC CHARACTERIZATION OF A COLLECTION OF ABBASID POTTERY EXCAVATED FROM UM QAIS (GADARA), JORDAN

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Abstract:
This study aimed to investigate and determine the raw materials, manufacturing technology, and provenance of a collection of Abbasid pottery sherds excavated from Um Qais, Northern Jordan. The samples were classified into three groups based on form and function, color, paste, and decorations. Chemical composition of the paste of the samples was analyzed using inductively coupled plasma-optical emission spectroscopy (ICP-OES). The mineralogical content and texture of the pastes were examined using polarized light microscope (thin sections) and X-ray diffraction (XRD) techniques. In addition to XRD results, the refiring test combined with the investigation of microstructures (vitrification) resulting from refiring using scanning electron microscopy (SEM), was used to determine the initial firing temperatures of the studied sherds. The results obtained from this study indicate that the pottery sherds were manufactured from calcareous clay. The Abbasid ceramists in Um Qais treated this clay according to the pot form to fulfill its function. X-ray diffractographs showed the formation of gehlenite and diopside minerals, and the SEM micrographs revealed that the micro-structure (vitrification) of the original samples reached extensive vitrification. Thus, the ceramists initially fired these pots at temperatures ranging between 800 and 950 °C in an oxidizing atmosphere. The raw materials used in the production of the sherds are available in Um Qais and its surrounding area, indicating that the study samples were locally made.

1. Introduction

Contrary to the organic materials and metals, the availability, durability and diversity of pottery uncovered during archaeological excavations make it a favorable cultural material, offering insights into the details of ancient human life. Pottery production underwent slow developments, beginning with simple forms and gradually evolving to meet the growing needs and demands of people throughout ancient periods, cultural differences, customs, traditions, social structures, technical capabilities, religion, availability of raw materials, and trade routes are among the factors that influenced the development of pottery production. This development was cumulative: for example, Umayyad ceramists were influenced by the methods and traditions late Byzantine pottery production and continued to produce both handmade and wheel-thrown pottery, in addition to molded oil lamps [1,2]. Abbasid pottery production experienced significant advancements, such as monochrome and polychrome glazed pottery [2], as well as golden luster pottery, which served as an alternative to gold and silver vessels [3]. Pottery production centers emerged in the Islamic world during this period, including in Basra, Kufa, and Samarra [4]. Archaeological excavations in Jordan, such as those at Jerash, Tabqat Fahel, and Um Qais, have yielded large quantities of Abbasid pottery, including tableware, glazed jars, oil lamps decorated with floral and geometric motifs typical of the Abbasid period [1,5,6]. The study of pottery manufacturing technology, raw materials used, typology, and decoration provides valuable insights into various aspects of ancient societies, such as their economy, trade routes, and the technical skill of the ceramists. These studies may rely on typology or scientific techniques (archaeometry). While typology helps describe the visual characteristics of paste wares and forms, suggesting possible dates, it does not provide any information about the raw materials, manufacturing technology, or the provenance. Archaeometry, on the other hand, can provide comprehensive answers to these questions [7]. This study aims to characterize the manufacturing technology and raw materials of a collection of Abbasid pottery sherds that excavated from the Decapolis site of Gadara (Um Qais) using an integrated approach, combining typology and archaeometry, to explore the skills and technical capability of Abbasid ceramist and provide insights into this period at Um Qais.

2. Gadara of the Decapolis (Um Qais)

The archaeological site of Gadara is about 28 km to the north of Irbid, fig. (1-a). The site has been inhabited since the Iron Age up to the present day. The archaeological remains are concentrated at the western part of site, which includes the Hellenistic–Roman acropolis (the high part), lying beneath the 19th century Ottoman village [8,9]. The Byzantine remains consist of a church and an agora [10,11]. However, Gadara flourished mostly during the classical periods, as evidenced by the still-standing monuments. There are strong indications that the site was also inhabited during the Islamic periods, namely, Umayyad [6,12], Abbasid, and Ayyubid/ Mamluk periods [6,13]. The site and its surroundings are characterized by a diversity of lithology and rock outcrops. According to Moh'd (2000: 17-23) [14] and Abed (2000: 214-216) [15], the lithology of the outcrops in the study area consists of the (older) Balqa Group, which includes several formations (Amman/Al Hisa, Muwaqqar, Umm Rijam, and Wadi Shallala). This group is of upper Cretaceous and Tertiary age and contains a variety of rock types, including carbonates (chalk, limestone, chalky limestone), marl, sandstone, chert, phosphate, and bituminous marl. A younger Tertiary group, the Jordan Valley Group, consists of three formations (Waqqas, Saham, and Irkheim), fig. (1-b). The rocks of this group are mainly conglomerate, marly silt, calcareous silt, with intercalations of massive limestone, clay, marl and travertine. Finally, quaternary basalt flows and tuff crop out in the study area.

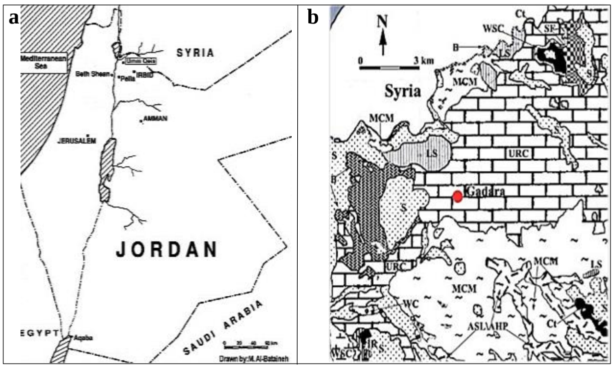

Figure (1) location map of **a.** Um Qais and other Decapolis cities north Jordan, **b.** the Formations and rocks that crop out at Gadra and its surroundings, modified (*After: Moh'd, 2000a* [16]; *Moh'd, 1997* [17]).

2.1. *Archaeological context of the samples*

Since 2011, the department of archaeology at Yarmouk University has undertaken systematic excavations at Gadara. The first season, supervised by Lamia El-Khouri, was conducted in area A, fig. (2-a). During this season, in addition to the classical remains, early Islamic constructions and the reuse of the older buildings indicated significant occupation. According to El-Khouri and Omoush [5], two Abbasid phases were recognized, fig. (2-b); the earliest phase (ca. 750-800 A.D.) and the second phase (800-1050 A.D.). The remains of the earliest phase consist of the reuse of older buildings or added walls, fig. (2-c). The second phase remains include a number of living rooms, compact floors, a tabun, and reused large pithos, fig. (2-d). Associated with these architectural remains, an abundance of Abbasid pottery was found in all the excavated squares. Among these, the study samples were selected.

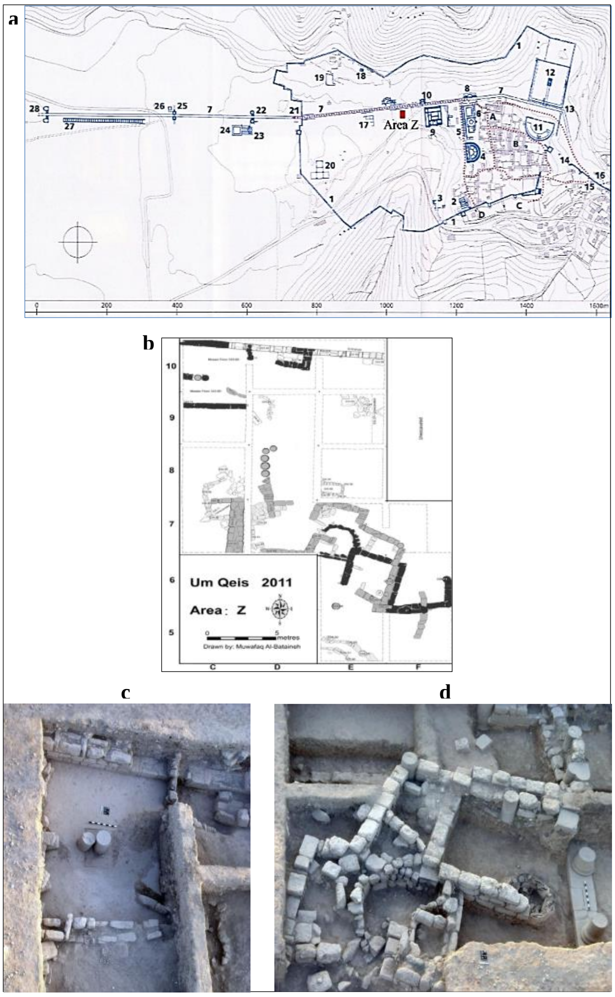

Figure (2) **a.** Gadara topographic map showing the distribution of the archaeological features at city, the 2011 season of excavation was in area Z (red square), **b.** the earliest (dark) and the second (grey) Abbasid phases as revealed by the 2011 excavation as Gadara, mosaic floor represent **c.** the Umayyad and the earliest Abbasid phase in squares (C9-10), **d.** Abbasid architectural remains as revealed in squares (E6-7, F6-7).

3. Materials and Methods

3.1. *Samples*

After reading, grouping, and dating the pottery, using the archaeological context, stratigraphy, and typology, a total of 26 pottery sherds were selected (based on the percentage of the available forms) to fulfill the aims of this study. The samples were then cleaned, drawn, photographed and classified based on their form into three groups: the jars group (samples UQ1, UQ2, UQ3, UQ,4, UQ5, UQ6, UQ7, UQ8), the jugs group (samples UQ9, UQ10, UQ11, UQ12, UQ13, UQ14, UQ15, UQ16, UQ17, UQ18, UQ19, UQ20, UQ21, UQ22, UQ23, UQ24) and the bowl group (samples UQ25, UQ26), tab. (1).

Table (1) the archaeological context, types, visual description and photos of the studied pottery sherds

S No.	Archaeological Context		Munsell color	Pottery typology	Thickness (cm)	Surface treatment	Photos (examples)
	Locus	Square					
UQ1	003/010	F7	2.5Y 8/2 pale Y	Jar, body sherd with handle	Handle: 2.3, body: 0.5	Rough both sides, wheel traces	
UQ2	020/01	F6	5Y 8/4 pale Y	Jar, handle	Handle: 1.4	Rough both sides, decoration on the handle	
UQ3	004/L	F5	2.5Y 8/2 pale Y	Jar, handle	Handle: 1	Rough both sides,	
UQ4	010/02	C10	2.5Y 8/3 pale Y	Jar, handle with body	Handle:1, body: 0.6	Rough both sides, wheel traces	
UQ5	020/01	F6	2.5Y 8/4 pale Y	Jar, handle with body	Handle: 1.6, body: 0.9	Rough both sides, wheel traces	
UQ6	010/02	C10	2.5Y 8/3 pale Y	Jar, handle with body	Handle: 2.3, body: 0.5	Rough both sides, wheel traces	
UQ7	004/L	F5	2.5Y 8/3 pale Y	Jar, rim (diameter= 7 cm) with body	Rim: 0.9, body: 0.5	Rough both sides, wheel traces	
UQ8	013/13	E6	2.5Y 8/4 Pink	Jar, body sherd	Body: 0.3	Rough both sides, wheel traces, brown decoration outer	

UQ9	003/09	F7	2.5Y 8/2 pale Y	Jug, rim (diameter= 7 cm) with body	Rim: 0.7, body: 0.5	Rough both sides, wheel traces
UQ10	011/07	C10	5Y 8/2 pale Y	Jug، handle with body	Handle: 1.8, body: 0.6	Rough both sides
UQ11	003/12	F7	5Y 8/2 pale Y	Jug، base (diameter= 7 cm)	Base: 0.5	Rough both sides, wheel traces
UQ12	003/09	F7	5Y 8/2 pale Y	Jug، nick with body	Body: 0.3	Rough both sides, wheel traces
UQ13	005/03	E6	5Y 8/3 pale Y	Jug، nick with body	Body: 0.3	Rough both sides, wheel traces
UQ14	003/12	F7	5Y 8/2 pale Y	Tall nick jug، loop handle	Handle: 0.7	Rough both sides
UQ15	003/010	F7	5Y 8/3 pale Y	Tall nick jug، loop handle	Body: 0.8	Rough both sides
UQ16	003/12	F7	5Y 8/3 pale Y	Jug، handle with body	Body: 0.5	Rough both sides, wheel traces, brown decoration
UQ17	004/01	E8	2.5Y 8/2 pale Y	Tall nick jug، loop handle	Handle: 1.2	Rough both sides
UQ18	003/12	F7	2.5Y 7/3 pale Y	Jug، handle	Handle: 1.1, body: 0.5	Rough both sides
UQ19	003/010	F7	5Y 8/2 pale Y	Jug، handle with body	Handle: 1, body: 0.4	Rough both sides, wheel traces
UQ20	010/010	C10	2.5Y 8/2 pale Y	Jug، nick with body	Rim: 0.5, body: 0.4	Rough both sides, wheel traces
UQ21	004/L	F5	2.5Y 8/2 pale Y	Jug, base (diameter= 7 cm) and body	Base: 0.5, body: 0.5	Rough both sides, wheel traces
UQ22	003/09	F7	5YR 6/3 pale RB	Jug, base (diameter= 10 cm) and body	Base: 0.7, body: 0.8	Rough both sides, wheel traces
UQ23	003/010	F7	5Y 8/3 pale Y	Jug, base (diameter= 7cm) and body	Base: 1.6, body: 0.4	Rough both sides, wheel traces
UQ24	003/09	F7	2.5Y 8/2 pale Y	Jug, base (diameter= 7cm) and body	Base: 0.9, body: 0.4	Rough both sides, wheel traces
UQ25	003/12	F7	2.5Y 8/3 pale Y	Globular bowl، body sherd	Body: 0.5	Rough both sides, wheel traces
UQ26	020/01	F6	2.5Y 8/2 pale Y	Deep bowl، body sherd	Body: 0.6	Rough both sides, wheel traces

3.2. Methods

To achieve the aims of this study, the selected samples were subjected primarily to archaeometric analyses, in addition to a brief typological description. The typology included drawing, visual description, and determination of their function. Each sample was then cut to obtain a representative slice using a Buehler Isomet™ low-speed diamond sawing machine. The surface was hand-ground using 800 µm, and 1000 µm tungsten carbide powder and water. The polished surface was mounted using Araldite; once dry, the molded sample was cut again to a thickness of about 0.8 mm. The final grinding and polishing were done manually using 800 µm, and 1000 µm tungsten carbide powder and water until the thickness reached 30 µm. The prepared thin sections were investigated for mineralogical content using a Leica polarized light microscope. Petrography aids in identifying the type, grain size and shape of non-plastic inclusions in pottery. In addition, powders of less than 63 µm grain size from each sample were subjected to X-ray diffraction (XRD) analysis using a Shimadzu XRD-600 (Shimadzu corporation). The XRD scanning process was conducted using the following parameters: a Cu–K generator with a maximum power output of 1.8 kW, a maximum voltage output of 60 kV, a maximum current output of 55 mA, and an angle range of 0°-60°. XRD data were used to confirm the results of petrography and identify unseen mineral phases that developed during firing, as well as very fine clay minerals. Both can provide insights into the initial firing temperatures of pottery. These petrography and XRD investigations were performed at the laboratory of the Faculty of Archaeology and Anthropology, Yarmouk University. For chemical analysis, a powder of 0.25 g of each sample was placed in 50ml polyethylene bottle, and 2 ml of 48% concentrated HF, 8 ml of 65% concentrated HNO_3 and 2 ml of 30 % concentrated H_2O were added. After dissolving the sample using a microwave, 5 ml of 4 % concentrated boric acid was added to eliminate the effect of HF. Finally, the sample was diluted 10 times to reach a total volume of 500 ml. The chemical composition of the samples was then obtain using ICP-OES (Perkin Elmer Optical Emission Spectrometer OPTIMA 7000DV) at the chemical laboratories of the Jordan Atomic Energy Commission. The Bulk chemical composition provides an indication of the nature of the clay used. Mineralogical and chemical data were analyzed to extract information about the raw materials and provenance of the studied sherds. Finally, four selected samples from all the typological groups (UQ 4, 16, 20 & 26) were chosen for refiring test. Each sample was divided into five parts: one part was kept as it, while the others were fired at temperatures of 750 °C, 800 °C, 850 °C and 950 °C, respectively, with a soaking time of one hour under oxidizing condition using Stuart Scientific furnace. Freshly fractured samples (obtained using a low-speed saw cutting machine) were then prepared, and micrographs were taken using an FEI Quanta 20 SEM at 300x and 2000x magnification. This was performed at the Geology dept., Yarmouk University. A comparison of the internal microstructure (the degree of vitrification) between the as-received state and refired samples can be used to estimate the initial firing temperatures of the studied sherds. Pottery passes through different stages of vitrification with increased firing temperatures. These stages can be recognized under a scanning electron microscope by amorphous areas and developed bloating pores, which increase in size, quantity and sphericity with higher firing temperatures [18-21].

3.3. Macroscopic description of the studied groups

The nicked eyes, simple lenses, ruler and Munsell color charts [22] were used to describe the color of the pastes, thicknesses, porosity, and surface treatments of the samples, tab. (1). A brief description of the three typological groups is outlined here, for more details, see tab. (1).

3.3.1. The jars (UQ1 - UQ8)

This group includes fragments of Jars, five handles (1-3 cm thickness), two body sherds (0.3-0.9 cm thickness), and one rim (0.9 cm thickness and 7 cm diameter). Except for sample UQ8 (pink color), the samples are yellow-cream in color. The pastes are characterized by fine fabric with very fine sand, and pores of less than 1 mm. Both inside and outside surfaces show traces of wheel use. Finally, samples UQ2 and UQ8 contain thumb decoration with brown paint, tab. (1) & fig. (3).

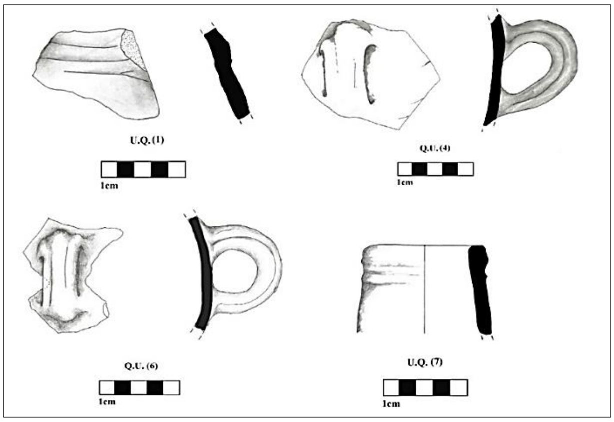

Figure (3) drawings of fragments of Jars (examples), UQ1 (body sherd), UQ4 and UQ6 (handles), and UQ7 (rim).

3.3.2. The jugs (UQ9 - UQ24)

This group consists of fragments of jugs, two rims/necks with body sherd (0.5-0.7 cm thickness and 7-15 cm diameter), seven fragments of handles (0.7-1.8 cm thickness), and five fragments of bases with body sherd (base thickness ranges from 0.5-1.6 cm, and diameter between 7-10 cm). The samples are pale yellow in color, with sample UQ9 featuring pale-red decoration. The pastes are of fine fabric (medium to very fine sand size) with pores of less than 1 mm. Both surfaces show traces of wheel use, tab. (1) & fig. (4).

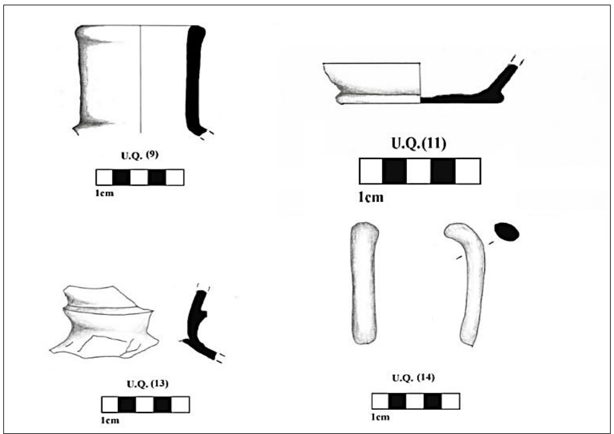

Figure (4) drawings of jugs fragments (examples). UQ9: rim with body fragment, UQ11: base, UQ13: nick, and UQ14: loop handle of tall nick jug.

3.3.3. The bowls (UQ25 - UQ26)

This group includes two body sherds of bowls: sample UQ25 is a fragment of globular bowl (0.5 cm thickness), and sample UQ26 is a fragment of a deep bowl (0.6 cm thickness). Both samples are of pale-yellow fine fabric (very fine sand size), with tough surfaces showing traces of wheel use, tab. (1) & fig. (5).

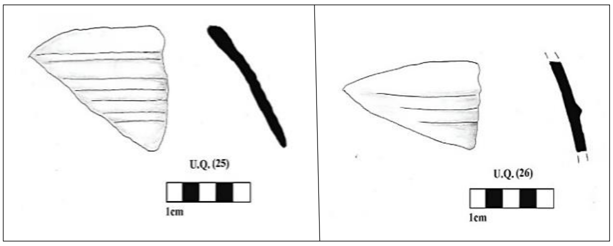

Figure (5) drawings of bowl fragments. UQ25 (ribbed body sherd), UQ26: (body sherd).

4. Results

4.1. Chemical (ICP-OES) results

The bulk chemical composition of the studied samples, tab. (2) reveals that the pottery sherds contain a high amount of silica (the average SiO_2 content across the groups ranges from 61.77 % to 65.91 %, a high amount of lime (CaO= 16.66 to 19.17 %), low amounts of alumina (Al_2O_3= 7.62 to 8.52 %), and low amounts of iron oxide (Fe_2O_3= 4.33% to 4.68 %). The clay used to produce the pastes is calcareous in nature. The ternary diagram of the bulk chemical composition, fig. (6) shows that the analyzed samples are relatively homogeneous, with slight differences observed, which are likely due to variations in the amounts of non-plastic inclusions in the pastes.

Table (2) chemical composition of the samples analyzed as measured using ICP-OES.

Sample	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	P_2O_5	SiO_2	TiO_2
UQ 1	8.92	22.72	5.94	1.03	2.66	1.29	0.73	55.6	1.11
UQ 2	8.26	18.15	5.2	1.08	2.45	1.03	0.88	61.93	1.02
UQ 3	8.36	21.22	5.08	1.31	2.24	0.92	0.81	59.14	0.92
UQ 4	7.39	17.56	4.44	0.63	2.09	1.1	0.77	65.14	0.88
UQ 5	9.09	22.09	5.26	1.41	2.14	0.87	1.16	57.02	0.96
UQ 6	8.23	23.03	5.3	0.87	2.36	1.19	0.93	57.13	0.96
UQ 7	7.01	19.08	4.33	1.06	2.77	0.98	0.6	63.34	0.83
UQ 8	10.87	9.49	1.85	1.41	0.53	0.24	0.16	74.88	0.57
Average	**8.52**	**19.17**	**4.68**	**1.10**	**2.16**	**0.95**	**0.76**	**61.77**	**0.91**
UQ 9	5.48	16.65	3.45	0.96	1.49	0.62	0.53	70.1	0.72
UQ 10	9.84	14.67	5.12	1.35	2.79	1.1	0.42	63.51	1.2
UQ 11	10.01	18.3	6.52	1.04	3.21	1.2	0.69	57.85	1.18
UQ 12	7.96	20.25	4.64	0.92	2.37	1.04	0.64	61.21	0.97
UQ 13	9.74	19.36	6.06	1.02	3.17	1.2	0.63	57.6	1.22
UQ 14	8.82	18.9	5.55	0.63	2.49	0.99	0.62	60.97	1.03
UQ 15	8.77	19.16	5.64	1.03	2.69	0.91	0.61	60.12	1.07
UQ 16	5.1	14.37	1.49	1.01	0.25	0.72	0.55	75.43	1.08
UQ 17	8.55	19.66	3.764	0.77	2.25	0.91	0.68	62.40	1.02
UQ 18	7.19	19.38	5.38	0.84	2.32	0.73	0.67	62.54	0.95
UQ 19	7.23	16.44	4.06	2.08	1.54	0.63	1	66.32	0.7
UQ 20	6.2	14.3	1.47	1.1	0.28	0.68	0.36	74.52	1.09
UQ 21	8	20.63	5.23	1.19	2.32	1.04	0.62	59.96	1.01
UQ 22	6.34	13.18	4.06	1.37	1.63	0.46	0.53	71.5	0.93
UQ 23	7.82	19.66	4.6	1.02	2.09	0.95	0.67	62.21	0.98
UQ 24	7.52	22.54	4.2	0.89	2.35	0.71	0.65	60.19	0.95
Average	**7.79**	**17.97**	**4.45**	**1.07**	**2.07**	**0.87**	**0.62**	**64.15**	**1.01**
UQ 25	7.3	16.59	4.28	1.08	1.82	0.68	0.66	66.74	0.85
UQ 26	7.95	16.73	4.38	1.06	1.77	0.8	1.3	65.09	0.92
Average	**7.62**	**16.66**	**4.33**	**1.07**	**1.79**	**0.74**	**0.98**	**65.91**	**0.89**

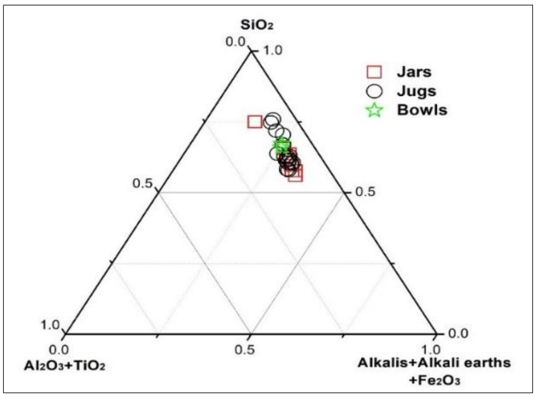

Figure (6) ternary diagram showing the silica-alumina-fluxes relation in the studied samples.

4.2. Mineralogical and petrographic results

The petrographic investigation of the samples, tab. (3) revealed two main fabrics: fine unimodal grain size and medium to coarse bimodal grain size fabrics. The fine fabric is found in half of the jar's samples (UQ1, 2, 5 and 6), which are characterized by light brown and light-yellow colors under plan polarized light (PPL) and yellowish brown and yellow colors under cross polarized light (CPL). This fabric consists of generally fine, unimodal grain size, well-sorted particles, with moderate to high amounts of non-plastic inclusions (20-40%), fig. (7-a). Quartz is the major constituent of the non-plastic inclusions, comprising 15-25% of rounded to subrounded fine grains. Micrite limestone fragments, which form 1-10%, are the other less abundant non-plastic inclusions, consisting of fine, rounded grains. Basalt fragments (UQ1, 2, and 5), fig. (7-b), iron oxide staining, and high amounts of foraminifera microfossils (UQ1, and 5) are also present as traces inclusions, fig. (7-c). Secondary calcite, as a post-depositional material, has invaded the cracks and the internal boundaries of the voids (UQ1, and 5), fig. (7-d). Most of the jug group samples belong to the fine fabric, with 14 of 17 samples falling into this category, except for samples (UQ9, 19, and 22). The colors of the samples and the type of non-plastic materials are the same as in the jar group, with the notable difference being a lower amount of non-plastic inclusions (less than 25%), fig. (10-e). These include fine subangular to rounded quartz grains (5-25%), fine rounded micrite limestone fragments (3-10%), and the same trace non-plastic inclusions (basalt, iron oxide and foraminifera). Finally, the bowl samples are also of the fine fabric type. The two samples are characterized by yellowish-gray colors under PPL and greenish-brown colors under CPL. They consist of fine unimodal grain size and rounded non-plastic inclusions with low amounts (15–20%), fig. (7-f). As in the previous groups (jugs and jars), the bowl pastes contain approx. 10 % fine subangular to rounded quartz grains, around 6 % fine rounded micrite limestone fragments, and small amounts of basalt fragments, foraminifera, and iron oxide.

Table (3) petrographic characteristics and mineral phases as detected by XRD of the studied pottery sherds

S. No.	Color		Grain size mode, sorting	Texture, amount of non-plastic %**	Non-plastic inclusions				Notes	XRD results ***
	PPL	*CPL*			*Type*	*Abundant %*	*Grain shape **	*Grain size ***		
UQ1	Ligh yellow	Greyish yellow	Unimodal, good	F, 25	Quartz	15	S. R-R	F-M	Iron oxide, basalt, high amounts of foraminifera, secondary calcite	Ma: Qz, Geh Mi:Cal, Pl T: Di, Hem
					Micrite limestone	10	R	Fi		
UQ2	Light brown	Yellowish brown	Unimodal, good	F-M, 20	Quartz	17	S. R	F-C	Iron oxide, basalt, fissures, plagioclase	Ma: Qz Mi: Geh, Pl T: Di, Hem, Cal
					Micrite limestone	3	R	F		
UQ3	Yellowish gray	Yellow	Bimodal, bad	F-C, 20	Quartz	16	S. R-R	F-C	Iron oxide, coarse basalt, elongated fissures, high amounts of secondary calcite	Ma: Qz, Geh Mi:Cal T: Di, Hem, Pl
					Micrite limestone	4	R	F		
UQ4	Greyish yellow	Yellow	Bimodal, bad	F-C, 35	Quartz	25	A- S. R	F-C	Iron oxide, coarse basalt, high amount elongated fissures and secondary calcite	Ma: Qz, Geh Mi:Cal, Pl T: Di, Hem
					Micrite limestone	7	R	F-C		
UQ5	Light greyish brown	Light yellowish brown	Unimodal, good	F, few M, 30	Quartz	20	S. R	F. few M	Iron oxide, plagioclase foraminifera in micrite, high amounts of secondary calcite in voids and fissures	Ma: Geh Mi: Qz, Cal, Pl T: Di, Hem
					Micrite limestone	10	A-S. R	F-M		
UQ6	Light brown	Yellowish brown	Unimodal, good	F, few M, 20	Quartz	15	S. R-R	F-M	Iron oxide, basalt, and a few elongated fissures	Ma: Geh Mi: Qz, Cal, Pl T: Di, Hem
					Micrite limestone	5	A-R	F-M		
UQ7	Yellowish gray	Greenish gray	Bimodal, bad	F, few M, 30	Quartz	15	S. R-R	F-C	Iron oxide, secondary calcite in fissures, basalt, high amounts of foraminifera	Ma: Qz, Geh Mi:Cal, Pl T: Di, Hem
					Micrite limestone	10	S. R-R	F		
UQ8	Light brown	Brown	Bimodal, bad	F-C, 35	Quartz	20	A-R	F-M	Iron oxide	Ma: Qz Mi: Geh T: Di, Hem, Cal, Pl
					Micrite limestone	10	S. R	F		
UQ9	Orangish brown	Yellow	Bimodal, bad	F-C, 15	Quartz	10	S. R-R	F-C	Iron oxide, basalt and plagioclase.	Ma: Qz Mi:Cal, Pl, Geh T: Di, Hem
UQ10	Light brown	Brown	Unimodal, good	Very F, 30	Quartz	20	S. A-S. R	F	Iron oxide, high amounts of voids, basalt, secondary calcite	Ma: Qz Mi:Cal, Pl, Geh, Di T:, Hem
					Plagioclase	5	R	F		
UQ11	Brown	Light brown	Unimodal, good	F, few C, 15	Quartz	11	S. R-R	F-M	Iron oxide	Ma: Qz, Geh Mi:Cal, Di, Pl T: Hem
					Basalt	4	S. R	M		
UQ12	Yellowish gray	Greenish gray	Unimodal, good	F, 20	Quartz	15	A	F	Iron oxide, mixed clay (calcareous)	Ma: Geh Mi: Qz, Di, Pl T: Cal, Hem
					Argillaceous	5	Patches	C		
UQ13	Light gray	Greenish gray	Unimodal, good	F, 20	Quartz	15	S. A	F	Iron oxide, Few medium grain quartz	
					Plagioclase	3	R	Very F		
UQ14	Light gray	Greenish gray	Unimodal, good	Very F-F, 10	Quartz	7	R	Very F	Iron oxide, secondary calcite	Ma: Geh Mi: Qz T: Di, Cal, Pl, Hem
					Micrite limestone	3	R	Very F		
UQ15	Brownish gray	Greenish gray	Unimodal, good	F, 15	Quartz	10	S. A	F	Iron oxide, plagioclase, secondary calcite in fissures	Ma: Qz, Geh Mi:Cal, Di T: Pl, Hem
					Micrite limestone	3	S. R	F		
UQ16	Greyish yellow	Greenish brown	Unimodal, good	Very F, 25	Quartz	20	A	F	Iron oxide, basalt, pyroxene secondary calcite in fissures	Ma: Qz Mi: Pl, Di, Geh, Hem T: Cal
					Plagioclase	5	S. R	Very F		
UQ17	Light gray	Greenish gray	Unimodal, good	F, 15	Quartz	7	R	F	Plagioclase, pyroxene, secondary calcite, foraminifera	Ma: Geh Mi: Qz T: Di, Cal, Pl, Hem
					Micrite limestone	8	R	F		
UQ18	Greenish yellow	Greenish yellow	Unimodal, good	F, 20	Quartz	15	S. R	F-M	Iron oxide, secondary calcite, basalt, plagioclase	Ma: Geh Mi: Qz, Hem T: Di, Cal, Pl
UQ19	Dark brown	Brown	Bimodal, bad	F-M, 40	Quartz	30	S. A-R	F-C	Iron oxide, plagioclase	Ma: Qz Mi: Di, Pl,Geh T: Cal, Hem
					Micrite limestone	7	S. R	F		
UQ20	Grayish brown	Yellowish brown	Unimodal, good	F, 15	Quartz	10	S. A	F	Iron oxide, high amount of secondary calcite, high amount foraminifera, basalt, mixed clay	Ma: Qz Mi: Di, Geh Cal, Pl, Hem
					Plagioclase	5	S. R	F		
UQ21	Light gray	Greenish gray	Unimodal, good	F, 15	Quartz	10	S. A	F	Iron oxide, secondary calcite, basalt, high amounts of foraminifera, pyroxene	Ma: Qz, Geh Mi: Pl, Di T: Cal, Hem

UQ22	Yellowish brown	Redish brown	Bimodal, bad	F-C, 25	Quartz	15	S. A-S. R	F-C	Iron oxide, foraminifera	Ma: Qz, Cal Mi: Geh T: Di, Pl, Hem
					Micrite limestone	10	S. R	F		
UQ23	Yellowish gray	Greenish yellow	Unimodal, good	F, 15	Quartz	7	S. R	F	Iron oxide, plagioclase, high amounts of foraminifera	Ma: Qz, Geh Mi:Cal, Pl T: Di, Hem
					Micrite limestone	5	R	F		
UQ24	Yellow	Greenish yellow	Unimodal, good	F, few M, 10	Quartz	5	S. R	F, few M	Iron oxide, plagioclase, high amounts of foraminifera	Ma: Geh Mi: Qz, Cal, Pl, Di T: Hem
					Micrite limestone	5	R	F		
UQ25	Greyish yellow	Greenish brown	Unimodal, good	F, few M, 20	Quartz	10	S. R	F, few M	Iron oxide, plagioclase, foraminifera	Ma: Qz, Geh, Pl, Cal T: Di, Hem
					Micrite limestone	10	S. R	F		
UQ26	Greyish yellow	Greenish brown	Unimodal, good	F, few M, 15	Quartz	10	S. A	F, few M	Iron oxide, secondary calcite, plagioclase, mixed clay	Ma: Qz, Geh Mi: Pl T: Cal, Hem, Di
					Micrite limestone	3	S. R	F		

:S**= sub, **A**= angular, **R**= rounded. **: **F**= fine, **M**= medium, **C**= coarse. ***: **Ma**= major, **Mi**= minor, **T**= trace. **Qz**= quartz, **Cal**= calcite, **Pl**= plagioclase, **Di**= diopside, **Geh**= gehlenite, **Hem**= hematite.*

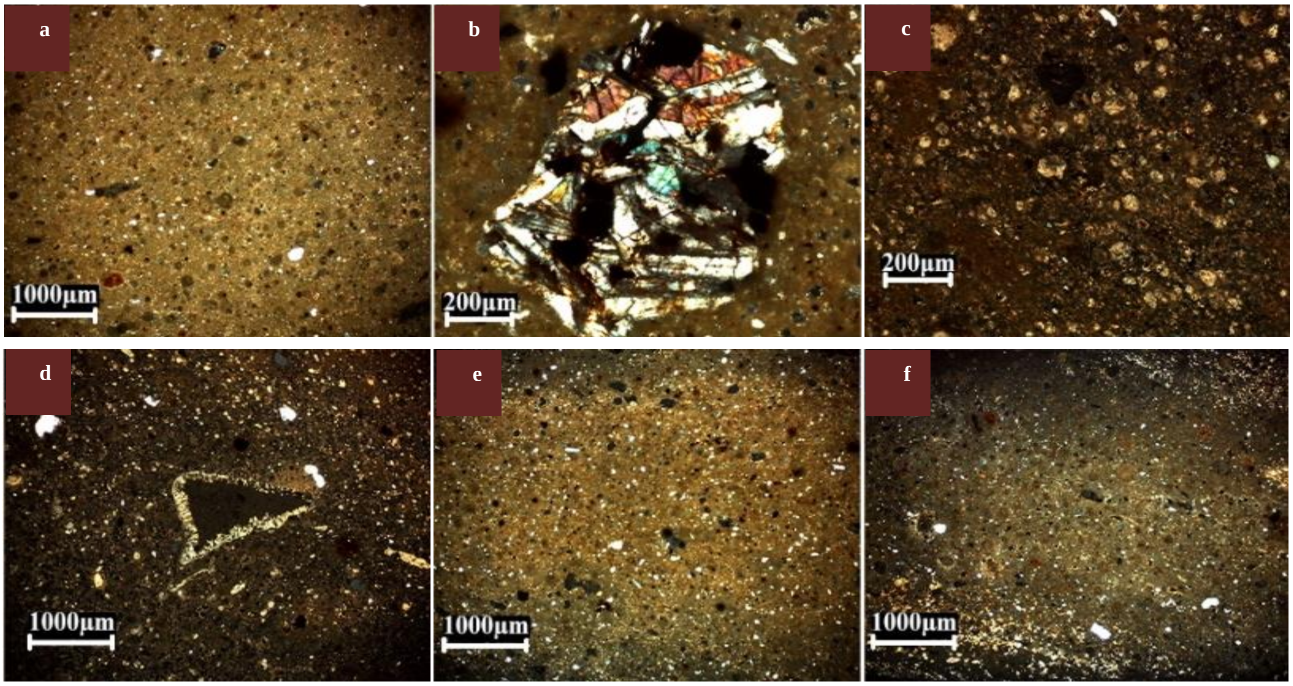

Figure (7) micrographs showing the fine fabric petrography; all images were teken under CPL; **a.** fine fabric of the jars, sample UQ6, **b.** basalt grain fine fabric of the jugs, sample UQ16, **f.** fine fabric of the bowls, sample UQ26.

Medium to coarse bimodal gran size fabric is less common in the studied samples. The jars samples UQ3, 4, 7, and 8, as well as the jugs samples UQ9, 19, and 22 belong to this fabric. The jar samples with this fabric consist of 15–25% medium to coarse angular to subangular quartz grains with a bimodal grain size, fig. (8-a). These grains are highly fractured, likely due to crushing during preparation of inclusion to in the pastes. The coarse angular grains in this fabric are typically interpreted as deliberately added by the ceramist [7,23,24,25]. The jug samples with medium to coarse fabric exhibit a bimodal grain size with a lower proportion of medium to coarse grains (less than 25%), fig. (8-b). As with the fine fabric group, basalt fragments, foraminifera microfossils, and iron oxide are common in the medium to coarse fabric group, figs. (8-c & d). The results of XRD, tab. (3) confirmed the observation made using microscopy. Quartz and calcite are either major or minor minerals in all samples, while plagioclase (a main constituent of basalt) is present as a minor phase and hematite is formed as a trace mineral in all samples, figs. (9-a, b & c). The XRD results, tab. (3) also show that the high-temperature aluminum silicate minerals (gehlenite and diopside) formed during initial firing process as either major or minor phases, in most of the samples.

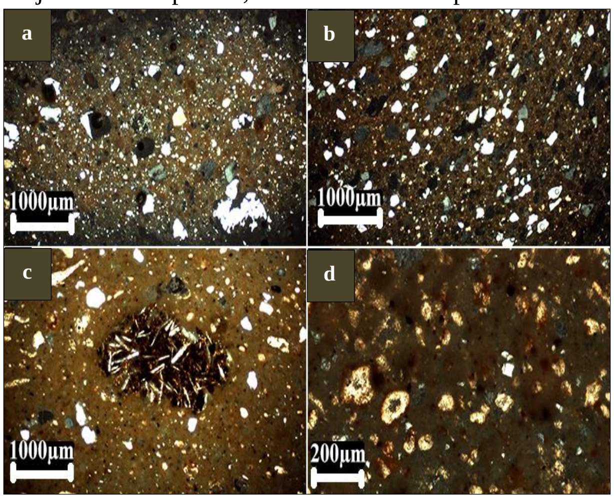

Figure (8) micrographs showing the coarse fabric petrography; all images were teken under CPL; **a.** medium to coarse fabric of the jars, sample UQ8, **b.** medium to coarse fabric of the jugs, sample UQ19, **c.** basalt grain in the coarse fabric, sample. UQ4, **d.** foraminifera microfossils in the matrix, samp.

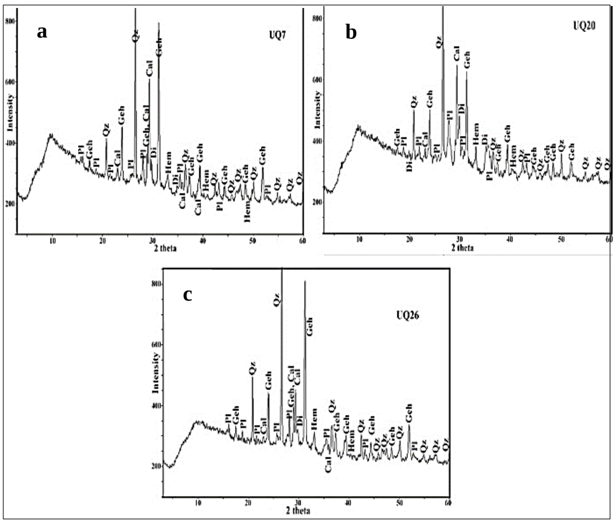

Figure (9) X-ray patterns showing the mineral phases in the three groups, where all phases exist in the three groups; **a.** jar sherd, **b.** jug sherd, **c.** bowl. Qz: quartz, Cal: calcite, Pl: plagioclase, Di: diopside, Geh: gehlenite, Hem: hematite.

4.3. *Microstructural investigation results*

The results of microstructure analysis (degree of vitrification) of the refired sample UQ4 (jar) showed no significant change. The shape and size of the bloating pores in the as-received sample, which is in the extensive vitrification stage with coarse bloating pores (40–100 µm), remained the same even after the sample was refired at 950 ˚C, fig. (10). A similar observation was made for sample UQ20 (jug), where the extensive vitrification in the as-received sample persisted even after refiring at 950 ˚C, fig. (11).

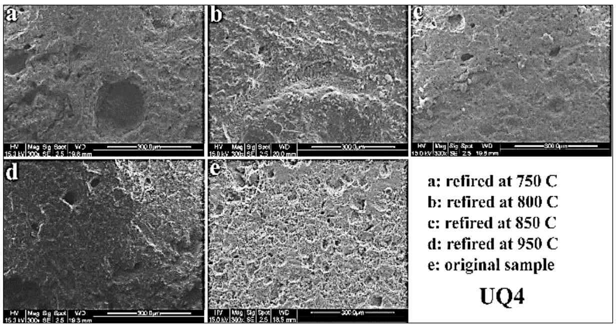

Figure (10) SEM photomicrographs of the microstructure of the refired fragments of sample UQ4 (jar).

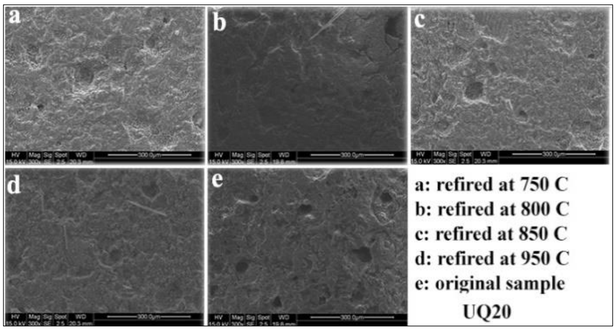

Figure (11) SEM photomicrographs showing the microstructure of refired parts of sample UQ20 (jug).

5. Discussion

5.1. *Raw materials and provenance*

The clay and non-plastic materials make up the pastes of pots, and therefore, they were investigated to gather information about the raw materials used by the Abbasid ceramists in producing different types of vessels. The previous results (chemical, petrography and XRD analyses) indicate that the Abbasid ceramists at Um Qais prepared the same paste using the available ferruginous calcareous clay [21,23] to manufacture both the daily-use pots and the jars. These pots were mad from clay extracted from the same source. A similar result was obtained by Alhbyshan [26] and El-Gohary, et al. [27]. However, the slight differences in silica content, i.e., the daily-use pots (jugs and bowls) contain higher amounts of silica than the jars, could be related to the larger amounts of quartz in their pastes. The Abbasid ceramists chose ferruginous calcareous clay, which naturally contains low amounts of fine non-plastic materials, to manufacture the daily-use pots (jugs and bowls), while they intentionally added coarse non-plastics to the paste of the jars. The fine texture and thin walls of smaller vessels, such as jugs, which may have been used to store liquids and perfumes, were designed to prevent the permeability of these liquids. On the other hand, the large size and thick walls of the jars required the addition of coarse non-plastic grains to improve rigidity and support the overall structure. This addition also helped reduce shrinkage during firing, and provided a degree of thermal insulation from the surrounding environment [7,28]. The raw materials utilized by the Abbasid ceramists, such as ferruginous high calcareous clay, basalt fragments, quartz, and the high content of foraminifera microfossils, are all available in the vicinity of Um Qais [14,15]. The Abbasid ceramists found the available raw materials sufficient to meet the functional requirements of the produced pots.

5.2. *Manufacturing technology*

Almost all the analyzed samples contain traces (circular lines) of the wheel-thrown process during on either the inner or outer surfaces, indicating that the Abbasid ceramists used the wheel to shape the pots they produced, which was common during this period [29]. Additionally, it appears that the ceramists mixed two types of clay to improve the properties of the calcareous clay when necessary. The color of the pottery can be used to indicate the firing condition, whether reducing or oxidizing [30,31]. All the studied sherds have light colors, such as light yellow, light brown, creamy, and light pink, tab. (1), which suggest that they were fired in oxidizing conditions. Gehlenite begins to form in calcareous clay during firing at around 800 ˚C and become stable at 950 ˚C [32]. Diopside forms at similar temperatures as gehlenite and becomes stable at around 1000 ˚C [33-35]. Both minerals were detected by XRD in all samples, indicating they were initially fired at temperatures around 950 ˚C. Furthermore, calcite was present in all samples. The presence of calcite in the samples fired at high temperature could be due to either post-deposition of secondary calcite from the burial context, fig. (7-d), or the high content of this mineral in the clay. Finally, the microstructures (degree of vitrification) of the refired samples confirm the XRD results, as the microstructures of the refired fragments did not change and remained the same as the original samples, even when refired up to 950 ˚C, fig. (10). This suggests that the initial firing temperature of these sample exceeded 950 ˚C. Calcareous clay was a common and preferred clay used by the ceramists in antiquity to manufacture ceramic pots. Its ease of shaping, ability to withstand thermal expansion, and overall favorable properties made it popular choice. The Abbasid ceramists used this clay and fired it at temperatures above 800 ˚C (around 950 ˚C) to avoid cracking, bursting and fragility during firing [36].

6. Conclusions

The Abbasid ceramists at Um Qais (Gadara) selected ferruginous calcareous clay (marl) to prepare the paste for all types of pots. They paid particular attention to using low amounts of fine non-plastic inclusions, mainly quartz, in the pastes of the jugs and bowls to produce fine fabric ware. In contrast, they added high amounts of medium to coarse quartz to produce coarse ware jars. Thus, the ceramists were meticulous in selecting and preparing pottery fabrics that met their functional requirements. The pastes also contain fragments of basalt and high amounts of microfossils, such as for a-minifera, which reflect the lithology of the Um Qais area, where limestone, marl, chalk and basalt rock are abundant. This indicates that the Abbasid pottery was locally made. The Abbasid ceramists used the wheel-throwing technique to shape the pots. After drying, they fired the pots in an open furnace with an oxidizing atmosphere, at temperatures exceeding 800 ℃ and reaching up to 950 ℃. This firing technique suggests that they took measures to avoid problems related to calcite decomposition, such as cracking, during the firing process. Further typological and archaeometric studies on Abbasid pottery are recommended to gain a deeper understanding of Abbasid period in Jordan. These studies could help confirm that occupation in Jordan during this period was not as disrupted as previously thought. On the contrary, this study indicates that there was continuous and flourishing occupation.

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