

A COMPARATIVE STUDY OF THE STRUCTURE AND CHEMICAL COMPOSITION OF BUFF WARE IN SHAHR-I SOKHTA WITH THE SURROUNDING SATELLITE SITES (CASE STUDY OF TEPE SADEGH), IRAN

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Abstract: At the same time, with the expansion and flourishing of the ancient site of Shahr-i Sokhta in southeastern Iran in the third millennium BC, many satellite sites formed around it. Population growth, productivity boom, specialization, and the development of this ancient city led its residents to seek habitation in new and separate regions in connection with the main center of the colony; that is, Shahr-i Sokhta, to create these satellite villages around it. Thus, in the second and third periods of Shahr-i Sokhta, various satellite sites around this ancient city appeared. The most important is in the mounds of the Rud-i Biyaban in the second period of settlement in Shahr-i Sokhta. Tepe Sadegh in the southern area of Qale Rostam is one of the most significant satellite sites of the third millennium BC. Its excavations began in 2009 by the Archaeological Committee of Sistan and Baluchestan University. The result of the excavations is the discovery of remarkable and valuable cultural findings, including architectural structures, pottery, stone artifacts, metal artifacts, and statuettes. Valuable discoveries from the excavations of this ancient site indicate the depth of extensive cultural relations of this site with Shahr-i Sokhta and other neighboring historical regions. This research is done based on the data obtained from laboratory studies of buff ware obtained from the Tepe Sadegh by various instrumental methods, including X-ray diffraction (XRD) and X-ray fluorescence (XRF). A comparative study of this experimental study results with the results of the analysis of buff ware samples obtained from Shahr-i Sokhta has indicated that the pottery discovered from both areas has a very similar structure and chemical composition. It suggests that the potters of Shahr-i Sokhta and the surrounding satellite sites, such as the Tepe Sadegh, may have used the same clay deposits to produce their pottery. In addition, laboratory experiments indicate that with the establishment of specialized centers for the production of pottery products in the form of satellite sites around Shahr-i Sokhta, the quality of ceramic products in terms of construction, compared to Shahr-i Sokhta, has improved somewhat.

Keywords: Tepe Sadegh, Shahr-i Sokhta, buff ware, comparative study, X-ray diffraction (XRD), X-ray fluorescence (XRF).

چکیده: همزمان با گسترش و شکوفایی محوطه باستانی شهر سوخته در جنوب شرق ایران در هزاره سوم قبل از میلاد، در پیرامون آن، محوطه‌های اقماری بسیاری شکل گرفت. افزایش جمعیت، رونق تولیدات و تخصص‌گرایی، همزمان با توسعه این شهر باستانی، موجب شد تا ساکنان آن به دنبال اسکان در مناطق تازه و مجزایی در پیوند با مرکز اصلی این کلتی؛ یعنی شهر سوخته، این روستاهای اقماری را در اطراف آن، ایجاد نمایند. بدین ترتیب، در دوران‌های دوم و سوم شهر سوخته، محوطه‌های اقماری مختلفی در پیرامون این شهر باستانی، پدید آمد که مهمترین آنها در تپه‌های رود بیابان در دوره دوم استقرار در شهر سوخته است. تپه صادق در حوزه جنوب قلعه رستم، یکی از مهمترین این محوطه‌های اقماری در هزاره سوم پیش از میلاد است که کاوش‌های آن از سال ۱۳۸۸ هجری شمسی، توسط هیأت باستان‌شناسی دانشگاه سیستان و بلوچستان آغاز شد که دستاورد آن، کشف یافته‌های فرهنگی بسیار مهم و با ارزشی، شامل: ساختارهای معماری، سفال، اشیای سنگی، اشیای فلزی، پیکرک‌ها و غیره است. کشفیات ارزشمند حاصل از کاوش‌های این محوطه باستانی، حاکی از عمق ارتباطات گسترده فرهنگی این محوطه با شهر سوخته و سایر مناطق تاریخی همجوار است. در این پژوهش که مبتنی بر داده‌های حاصل از بررسی‌های آزمایشگاهی سفالینه‌های نخودی به‌دست‌آمده از تپه صادق به روش‌های مختلف دستگاهی، اعم از: پراش پرتوی ایکس (XRD) و فلورسانس اشعه ایکس (XRF) است؛ مقایسه تطبیقی نتایج حاصل از این پژوهش تجربی با نتایج آنالیز نمونه‌های سفال نخودی به‌دست‌آمده از شهر سوخته، نشان داده است که سفال‌های مکشوفه از هر دو منطقه، دارای ساختار و ترکیب شیمیایی بسیار مشابهی می‌باشند که احتمالاً، سفالگران شهر سوخته و محوطه‌های اقماری پیرامون آن، همچون تپه صادق از کانسارهای رسی یکسانی در تولید محصولات سفالی خود بهره می‌برده‌اند. علاوه بر این، مطالعات آزمایشگاهی انجام شده، نشان داد که با ایجاد مراکز تخصصی تولید فرآورده‌های سفالی در قالب محوطه‌های اقماری در اطراف شهر سوخته، کیفیت محصولات سفالی به لحاظ ساخت، نسبت به شهر سوخته تا حدی ارتقاء یافته است.

کلمات کلیدی: تپه صادق، شهر سوخته، سفال نخودی، مطالعه تطبیقی، پراش پرتوی ایکس (XRD)، فلورسانس اشعه ایکس (XRF).

I. Introduction

The ancient site of the Shahr-i Sokhta near Zabol in Sistan and Baluchestan province is one of the ancient civilizations in southeastern Iran. In fact, Shahr-i Sokhta is the most important ancient site of Sistan, located next to the Helmand River delta on the highest edge of the northwestern point of the old delta on the mounds of Ramrud Terrace (Sajjadi, 2003: 21). At the end of the Chalcolithic age, between 3200-4000 BC in this region,

due to the Helmand River and suitable climatic conditions, people of Indo-European descent built a large and advanced city that today is known as Shahr-i Sokhta. (Costantini, 1977: 88). The first scientific report on Shahr-i Sokhta was published by Stein in 1916 (Mortazavi, 2004: 43). In this study, Stein identified a series of ancient sites around Ramrud near the old bed of the Rud-i Biyaban, the largest of which was Shahr-i Sokhta (Tosi, 1968: 13). The first scientific archeological

excavations in this archaeological site were started by the ISMEO Archaeological Board from Italy under the supervision of Maurizio Tosi in 1967 and continued until 1978 (Sajjadi, *et al.*, 2003: 196, 271). The second round of archeological excavations in Shahr-i Sokhta began in 1997 by the Iranian Archaeological Board under the supervision of Seyed Mansour Seyed Sajjadi and continues (Seyed Sajjadi, 2006: 17).

Archaeological excavations in this area over the past few decades indicate that Shahr-i Sokhta had four different settlement periods, ranging from 3200 BC to 1800 BC. Studies conducted by archaeologists in this area are Protohistory, indicating the existence of eleven cultural layers (Tosi, 1973: 68-80). Archaeological excavations of Shahr-i Sokhta showed that this ancient city was founded in the first period (2800-3200 BC), that in the second period of its establishment (2800-2500 BC), it had achieved the peak of its development, expansion, and prosperity and that it disappeared at the end of the fourth period in 2000 or 1800 BC (Seyed Sajjadi, 2006: 17).

Continuation of archeological excavations in this ancient city by the Iranian delegation headed by Seyed Mansour Seyed Sajjadi showed that the area of this city included an area of 151 hectares (Seyed Sajjadi, 1995: 169). Archaeological excavations carried out by Italian and Iranian archaeologists over the decades have resulted in the discovery of thousands of valuable cultural finds of great diversity and richness. From this ancient city, many study pieces, including pottery, artifacts, and stone pieces from marble and lapis lazuli, have been obtained, indicating that this ancient city was a center for the production and distribution of such products (Tosi, 1978: 55). Simultaneously, with the expansion and prosperity of Shahr-i Sokhta and seeking to increase production, trade, and commerce, the cultural connections of this ancient city with neighboring and distant areas expanded. On the other hand, the population of this city also increased. Increasing the population of the city and specialization in it caused many satellite villages to appear around it (Allahpour *et al.*, 2019: 212).

Tepe Sadegh is one of the most important satellite sites of Shahr-i Sokhta, located 75 km southwest of Zabol city, near and south of Rostam Castle historical monument. This historic almost oval is located 13 km southwest of Shahr-i Sokhta and is about 6 meters high from the surrounding flat land. Various cultural finds have been obtained from the surface of this mound, including pottery, tool stone chips, stone tools, sculptures, kiln wasters, and bronze metal parts. Among these, pottery finds are more important in terms of quantity and quality (Allahpour *et al.*, 2017: 350-362).

This satellite mound of Shahr-i Sokhta was first identified by the Sistan Archaeological Board headed by Seyed Rasoul Mousavi Haji and Reza Mehr Afarin. The

initial registration and survey of this ancient mound were done by the same committee. Examination of its surface pottery showed that this place is one of the satellite villages of Shahr-i Sokhta, which was inhabited in the third millennium BC. The first chapter of archeological excavations in Tepe Sadegh began in November 2009, under the supervision of Ruhollah Shirazi and Mohammad Mehdi Tavassoli. In the following years, these excavations in the form of a training program for practical excavations courses for archaeology students of Sistan and Baluchestan University, and under the supervision of faculty members of this group, continued (Allahpour, 2011: 46).

During the excavations carried out in Tepe Sadegh by the Archaeological Board of Sistan and Baluchestan University over several seasons, different types of pottery with pastes in various colors, including buff, red, and gray, with different qualities in terms of make were obtained in a rough, medium to fine texture. Most of the pottery found from this ancient mound includes: buff ware and red and gray paste pottery are in the next ranks, respectively. The amount of gray pottery found in this satellite area of Shahr-i Sokhta is much less than that of buff and red pottery. Most of the pottery discovered from this ancient site has a medium-quality construction. These potteries can be seen in different forms, including cups, bowls, plates, pots, jars, etc., which are made by two methods: handmade and wheel-making (Shirazi, 2017).

Although most of the pottery obtained from Tepe Sadegh is of simple and unadorned type, in the category of painted pottery discovered, from different methods and techniques, such as painting, carving, augmentation, molding, and carving used to decorate them. The content of motifs used in decorating the painted pottery of Tepe Sadegh are geometric, plant, animal, and compositional motifs. The most obvious method of decoration used in the painted pottery of this ancient site is the use of the monochrome painting method, with colors, including black, red, brown, etc. In reviewing and dating the pottery finds obtained from this satellite village of Shahr-i Sokhta, in general, it can be said that most of the pottery belongs to the Bronze Age in the southern plain of Sistan with the third and fourth periods of Shahr-i Sokhta and other satellite areas. This ancient city is simultaneous (Shirazi, 2016).

Most of the studies on pottery found in the Shahr-i Sokhta focus on their historical studies, and little experimental research has been done on laboratory artifacts from this important Bronze Age site. Laboratory study by Moradi and his colleagues by XRF method on some of the pottery of the Shahr-i Sokhta in 2013 showed that limestone clay was used in the construction of the pottery of the Shahr-i Sokhta and

most of the pottery discovered from these ancient sites except a few are local (Moradi *et al.*, 2013).

Elemental analysis of the body of some of the pottery pieces of the Shahr-i Sokhta by Sarhadi Dadian and others, using the XRF method, showed that most of the buff pottery pieces are locally produced, but the red and gray pottery pieces are probably non-native and imported (Sarhadi Dadiyan, *et al.*, 2015).

Javanshah's laboratory studies by various methods of instrumental analysis including XRD, XRF, SED-EDS, and petrography on Shahr-i Sokhta pottery showed that the studied pottery was made of sandy clay that has a granular texture with a high amount of silica and is baked at 900 °C under oxidation conditions and all of them are native to the region (Javanshah, 2018).

Eftekhari and his colleagues 2021 examined several other potteries discovered in the Shahr-i Sokhta by XRF, SED-EDS, and petrographic methods. The results of these experiments showed a large number of potteries from Shahr-i Sokhta has been a matrix of fine-grained clay, among which samples of red and gray pottery are probably non-native and buff pottery is native to the region (Eftekhari *et al.*, 2021).

In this study, the bodies of a number of samples of buff ware pottery obtained from the archaeological excavations of Tepe Sadegh were examined in a comparative study with colored buff ware found in Shahr-i Sokhta by instrumental analysis. The most important issue in this study is a comparative study of the structure and chemical composition of buff ware in Shahr-i Sokhta with the surrounding satellite areas in the Bronze Age in comparison with each other. Technical developments, similarities, and differences in the structure and chemical composition of the body of these potteries can be examined and identified.

II. Materials and methods

This applied research has been done using experimental-analytical methods, in which various methods have been used to collect research information and data, such as library study, field study, and experimental methods with laboratory study. For this purpose, in this study, three pottery shards of plain buff ware obtained from Tepe Sadegh and three buff ware pots obtained from Shahr-i Sokhta excavations were selected for and for comparative study with each other (Fig. 1 and 2). It has been studied experimentally using various instrumental analysis methods, such as X-ray diffraction (XRD) and X-ray fluorescence (XRF). To know the mineralogical structure and chemical composition of the body of buff ware pottery obtained from these two ancient sites that are in deep cultural connection with each other, the results of a laboratory study of these two groups of pottery discovered from

these two ancient sites should be compared with each other. In this way, it becomes clear to us the changes, differences, and similarities in the crystal structure and phases in the pottery body of these two groups and the chemical composition of the elements in the soil used to make them, which is used as the main raw material for their production. It has been based on the use of clay obtained from local clay deposits in the area.

III. Results

The study and analysis of the body of buff ware were tested in these two areas by different methods of instrumental analysis, and the results of this study in the samples of colored buff ware discovered from Tepe Sadegh in comparison with buff ware obtained from Shahr-i Sokhta are as follows:

III.1. Appearance observations and sampling of colored buff ware

The pottery samples studied and tested in this study include three pieces of plain buff ware study belonging to Tepe Sadegh, in comparison with the three buff ware vessels discovered from Shahr-i Sokhta. The recent samples were in the form of jars and glasses (Fig. 1 and 2). The characteristics of the pottery studied in this research are presented in Tables 1 and 2 as follows. In order to study the laboratory structure and chemical composition of the elements of pottery, their bodies were sampled in a very small amount from both groups, to study and analyze the samples taken by different methods of instrumental analysis. Then, the results obtained from the analysis of the pottery body in these two ancient sites should be compared with each other.

III.2. Study of the structure of the body of pottery by X-ray diffraction (XRD) method

XRD was used for the identification of mineral phases of the sampled raw material. XRD analyses were performed on a Philips diffractometer under the following conditions: 5–60° 2 θ , radiation of CuK α 1,2 with a step scan. Samples were dried in an oven at 50°C for 1 h. After drying, each sample was pulverized manually in an agate mortar and then analyzed. To study the structure of the body of the desired clay samples and identify the constituent phases and their mineralogical composition, a very small amount of sample was taken from the body of each of the studied buff ware from Shahr-i Sokhta and Tepe Sadegh. X-ray diffraction (XRD) was tested and analyzed. The results and data obtained from the analysis of the pottery body in these two ancient sites were compared with each other based on the diffraction pattern and the phase analysis of their diffraction spectroscopy. The results of these studies are as follows (Fig. 3 and 4) (Tables 3 and 4).



Figure 1. Buffware pieces N25, N44, and N65 discovered from Tepe Sadegh.

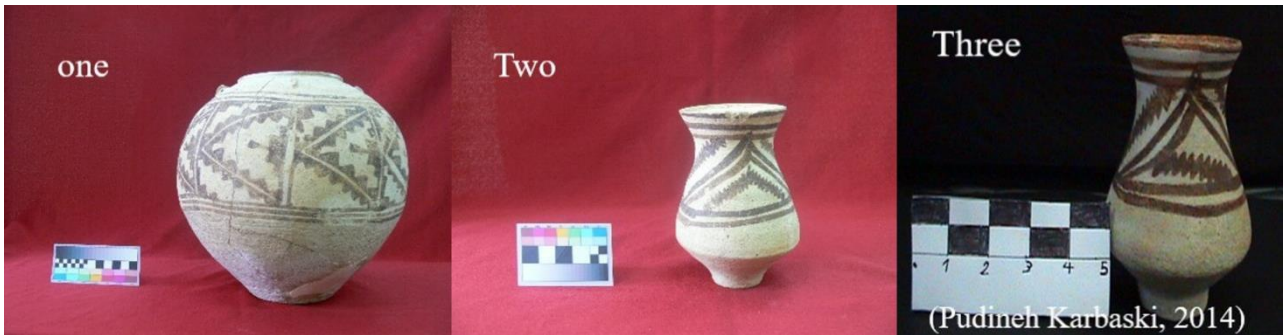
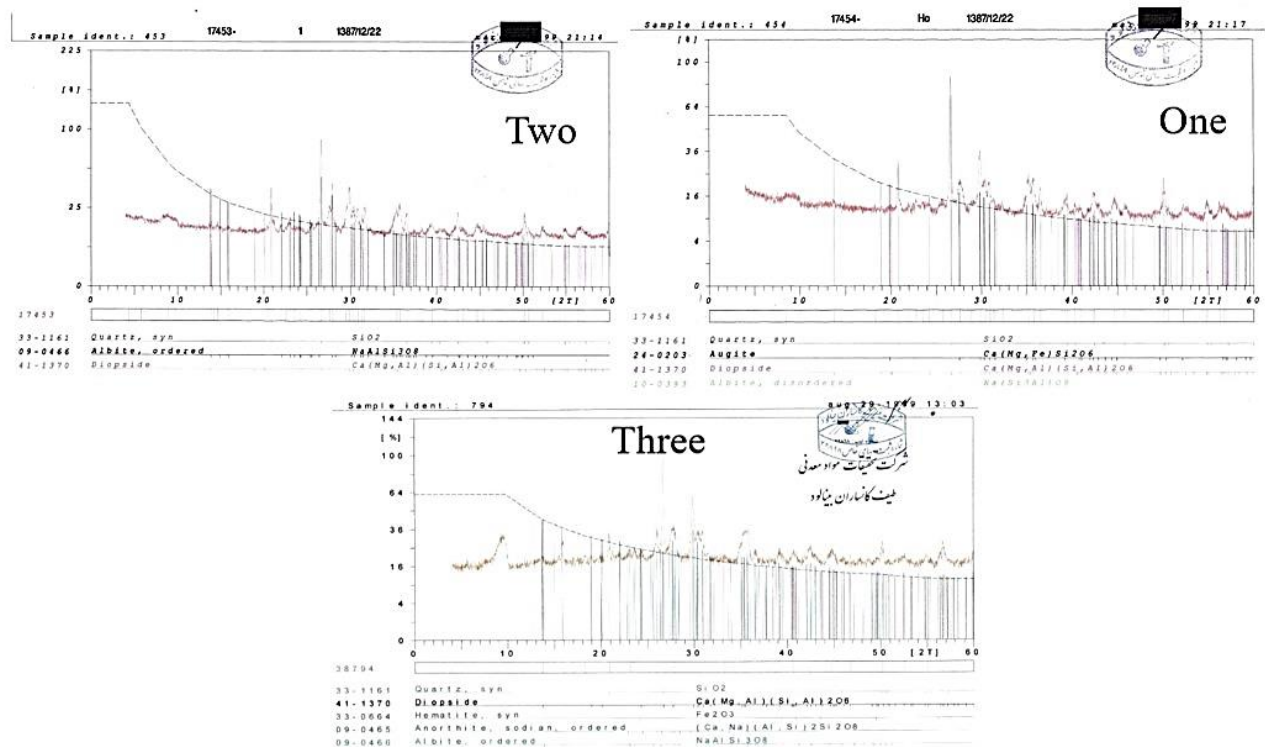


Figure 2. Buffwares number one, two, and three discovered from Shahr-i Sokhta.



(Pudineh Karbaski, 2014)

Figure 3. X-ray diffraction spectroscopy (XRD) of N25 and N65 buff ware pieces discovered from Tepe Sadegh.

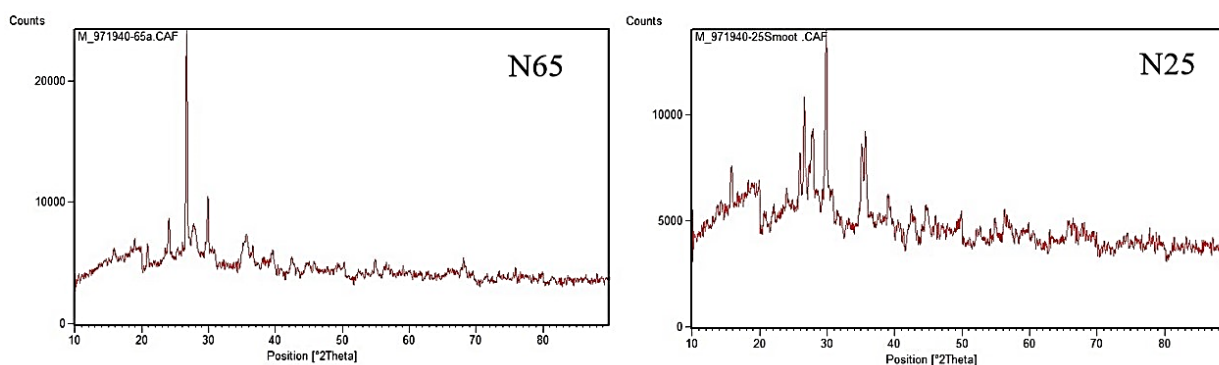


Figure 4. X-ray diffraction spectroscopy (XRD) of buff wares number one, two, and three discovered from Shahr-i Sokhta.

Table 1. Specifications of the studied buff ware pieces, discovered from Tepe Sadegh.

	Pottery piece number one	Pottery piece number two	Pottery piece number three
Pottery Code	Ts: 1396 T: 9 Su :69 N:25	Ts: 1396 T: 9 Su :6 N:44	Ts: 1396 T: 10 Su :1 N:65
Place of discovery	Tepe Sadegh	Tepe Sadegh	Tepe Sadegh
Year of discovery	2017	2017	2017
Trench code and number	T: 9	T: 9	T: 10
Layering unit	Su :69	Su :6	Su :1
Type of piece	Floor (base)	Edge (container opening)	The body of the vessel
Type of pottery	Simple buff ware	Painted buff ware	Simple buff ware
The historical period	third period	third period	third period
Dating	Bronze Age, millennium 3-4 BC	Bronze Age, millennium 3-4 BC	Bronze Age, millennium 3-4 BC
Substrate	deep	superficial	superficial
Pottery base color	buff	buff	buff
Filler type	sand	sand	sand
Forming method	Wheel maker	Wheel maker	Wheel maker

Table 2. Specifications of the studied buff ware, discovered from Shahr-i Sokhta.

	buff ware number one	buff ware number two	buff ware number three
Place of discovery	Shahr-i Sokhta Cemetery	Shahr-i Sokhta Cemetery	Shahr-i Sokhta Cemetery
Year of discovery	2006	2006	2005
Code and Trench number	MJN6700	MJN6700	MJJ
Funeral number	6703	6703	-----
Pottery shape	jar	pear-shaped cup	pear-shaped cup
Type of pottery	Painted buff ware	Painted buff ware	Painted buff ware
The historical period	First period	Second period	Second period
Dating	Bronze Age, 2900 BC	Bronze Age, 2800-2900 BC	Bronze Age, 2800-2900 BC
Substrate	deep	superficial	deep
Pottery base color	buff	buff	buff
Filler type	sand	sand	sand
Forming method	Wheel maker	Wheel maker	Wheel maker

Table 3. Results of structural study of a buff ware body discovered from Tepe Sadegh by X-ray diffraction (XRD) method.

Pottery number	Combination mineralization and identified phases	Chemical properties of phases	PDF Number Card
buff ware N25	Augite	$\text{Ca}(\text{Mg,Fe})\text{Si}_2\text{O}_6$	00-024-0203
	Diopside	$\text{Ca}(\text{Mg, AL})(\text{Si, Al})_2\text{O}_6$	01-071-1067
	Huntite	$\text{Mg}_3\text{Ca}(\text{CO}_3)_4$	00-006-0462
buff ware N65	Quartz	SiO_2	00-005-0490
	Epidote	$\text{Ca}_2(\text{Al,Fe})_3(\text{Si}_2\text{O}_7)(\text{SiO}_4)(\text{OH})_2$	00-045-1446
	Chloritoid	$\text{Al}_5\text{Fe}_7\text{Mg}_{1.2}\text{Si}_8(\text{OH})_{13.6}\text{O}_{40}$	01-072-1183
	Sodium Silicate	Na_4SiO_4	00-036-0112

Table 4. Results of a structural study of a buff ware body discovered from Shahr-i Sokhta by X-ray diffraction (XRD) method.

Pottery number	Combination mineralization and identified phases	Chemical properties of phases	PDF Number Card
buff ware number one	Quartz	SiO_2	33-1161
	Augite	$\text{Ca}(\text{Mg,Fe})\text{Si}_2\text{O}_6$	24-0203
	Diopside	$\text{Ca}(\text{Mg, AL})(\text{Si, Al})_2\text{O}_6$	41-1370
	Albit	$\text{Na}(\text{Si}_3\text{Al})\text{O}_8$	10-0393
buff ware number two	Quartz	SiO_2	33-1161
	Albit	$\text{Na}(\text{Si}_3\text{Al})\text{O}_8$	09-0466
	Diopside	$\text{Ca}(\text{Mg, AL})(\text{Si, Al})_2\text{O}_6$	41-1370
buff ware number three	Quartz	SiO_2	33-1161
	Diopside	$\text{Ca}(\text{Mg, AL})(\text{Si, Al})_2\text{O}_6$	41-1370
	Hematite	Fe_2O_3	33-0664
	Anorthite	$(\text{Ca, Na})(\text{Al, Si})_2\text{Si}_2\text{O}_8$	09-0465
	Albit	$\text{Na}(\text{Si}_3\text{Al})\text{O}_8$	09-0466

A study of the structure of a buff ware body of the Tepe Sadegh satellite site in comparison with painted buff ware obtained from Shahr-i Sokhta was studied to identify the mineral composition and phases formed in the pottery body in both groups. X-ray diffraction method showed that the phases identified in both groups of buff wares in these two areas are very similar to each other and in many cases similar. In all samples of buff ware studied, quartz, augite, and diopside minerals are the same, and the other identified phases are similar in terms of chemical composition and the classification of crystalline structure and are in the group of silicate minerals (Tables 3 and 4).

III.3. Analysis of the composition of pottery body elements by X-ray fluorescence (XRF) method

The samples were cut, pulverized, pressed into powder pellets, and analyzed by X-ray Fluorescence Spectroscopy. Loss on ignition (LOI), which is a measure of the content of carbon dioxide and any other volatile components, including organic materials, was determined by weighing the samples before and after heating at 1000°C.

Using the X-ray fluorescence (XRF) method, the results of qualitative and quantitative analysis of the chemical composition of the elements in the body of

buff ware of Tepe Sadegh in comparison with the samples of buff ware discovered from Shahr-i Sokhta, indicated that the chemical composition of the body buff ware in both ancient sites have many similarities in comparison with each other, both qualitatively and quantitatively, is very close to each other. The amount of SiO_2 silica in Tepe Sadegh buff ware is between 55.3 to 55.7% by weight, and in Shahr-i Sokhta, this amount in the body of the buff ware tested is 46.75 to 51.5%.

The amount of alumina in the body of Tepe Sadegh buff ware is 14.3% to 15.5%, and in similar pottery in Shahr-i Sokhta, the amount of alumina is 8.64% to 11.99%. Similarly, the amount of iron oxide in Tepe Sadegh buff ware is 5.4 to 6.7 percent, and in Shahr-i Sokhta is 4.98 to 5.58 percent (Tables 5 and 6).

On the other hand, the composition and amount of fluxes used in the body of pottery of Tepe Sadegh and Shahr-i Sokhta, including calcium oxide, sodium oxide, and magnesium oxide, were studied. They are very similar to each other, and the percentage of their presence in the pottery samples of the two areas is close, so that the amount of calcium oxide in Tepe Sadegh pottery is 9.5% to 16.1%16.1%, and in Shahr-i Sokhta buff ware, the amount of this important flux is 10.70% to 14.04%. Magnesium oxide is 3.5 to 9.3 percent in Tepe Sadegh buff ware, and 6.69 to 9.67 percent in the body of Shahr-i Sokhta buff ware. The amount of these

compounds in both groups of pottery obtained from these two areas is similar to each other (Tables 5 and 6).

The situation is similar for other compounds in the body of buff ware in these two ancient sites in comparison with each other, such as different impurities like titanium oxide, sulfur oxide, barium, strontium, and chlorine (Tables 5 and 6).

Overall, due to the diffraction measurement and mineralogical composition of the studied pottery, the

findings of the analysis of the buff ware body obtained from these two Bronze Age archeological sites in comparison with each other are in good agreement.

It was shown that the composition of the body of buff ware discovered from the satellite village of Tepe Sadegh is similar to the buff ware obtained from Shahr-i Sokhta in terms of the chemical composition of the elements that make up the body.

Table 5. Results of elemental analysis of the body of buff ware discovered from Tepe Sadegh by X-ray fluorescence (XRF) method.

Pottery sample	Pottery number one N:25	Pottery number two N:44	Pottery number three N:65
Na ₂ O	1.7	1.6	1.3
MgO	5.3	8.6	9.3
Al ₂ O ₃	15.5	14.3	14.5
SiO ₂	51.3	54	55.7
P ₂ O ₅	0.30	0.24	0.36
SO ₃	---	0.34	---
Cl	0.096	0.054	0.048
K ₂ O	0.13	0.25	0.36
CaO	16.1	12.9	9.5
TiO ₂	0.53	0.48	0.44
MnO	0.025	0.024	0.024
Fe ₂ O ₃	6.7	5.5	5.4
SrO	0.017	0.026	0.031
BaO	0.010	0.013	0.017
LOI	1.90	1.51	2.75

Table 6. Results of elemental analysis of the body of buff ware discovered from Shahr-i Sokhta by X-ray fluorescence (XRF) method.

Compound	Pottery number one (wt.%)	Pottery number two (wt.%)	Pottery number three (wt.%) (Pudineh Karbaski, 2014)
Na ₂ O	1.64	3.69	3.76
MgO	8.66	9.67	6.69
Al ₂ O ₃	10.32	8.64	11.99
SiO ₂	50.62	46.75	51.05
P ₂ O ₅	1.36	0.43	0.33
SO ₃	0.32	2.45	0.98
Cl	0.10	0.93	0.058
K ₂ O	2.07	2.69	1.48
CaO	14.04	13.46	10.70
TiO ₂	0.47	0.45	0.54
MnO	0.09	0.10	0.10
Fe ₂ O ₃	4.98	4.99	5.58
SrO	0.071	0.043	0.015
BaO	0.036	0.024	0.030
LOI	5.16	5.62	6.64

IV. Discussion of research findings

The results of the analysis of the structure and chemical composition of buff ware discovered from the satellite site of Tepe Sadegh in comparison with the colored buff ware obtained from Shahr-i Sokhta indicate the similarity of the structure and chemical composition of the body of buff ware in both archaeological sites. The presence of similar and identical phases in the body of buff ware in both sites, as well as the very similar chemical composition in terms of the composition of the constituent elements in terms

of quality and quantity, indicate that probably in both ancient sites of the same clay deposits to supply soil used to make buff ware in the Bronze Age. The use of similar resources and raw materials in supplying the soil used to prepare pottery clay in both areas has caused after firing pottery products in the body of buff ware in both Tepe Sadegh and Shahr-i Sokhta areas, the presence of mineral compounds is the same, such as quartz, augite, diopside, and other silicate minerals.

On the other hand, the study and elemental analysis of the chemical composition of the pottery body also

showed that the amount of important and main chemical compounds and elements in the pottery body in both groups of buff ware in these two ancient sites are very similar to each other. In addition, the study of the crystal structure of the Tepe Sadegh pottery body in comparison with the samples of Shahr-i Sokhta shows that the quality of construction and firing of pottery and soil used have changed to some extent in the pottery of Tepe Sadegh.

As the results of diffraction analysis of pottery bodies have shown, in the mineralogical composition of Tepe Sadegh buff ware in comparison with Shahr-i Sokhta samples, although the same phases with similar chemical composition and crystal structure are observed, in Shahr-i Sokhta buff wares, there is a lot of scattering in the type of phases in the pottery body of this ancient site. That is why in the body of these potteries we are faced with the multiplicity of crystalline phases in their diffraction spectrum. On the other hand, the study of the composition of the elements that make up the body of buff ware in these two areas in comparison with each other also shows the same thing. The amount of silica in the Tepe Sadegh pottery body has been increased to 55%, which results in combination with various flux compounds found in the pottery body of this area, especially calcium oxide in the pottery body, which causes better durability and strength of the product body.

In addition, according to the results of the analysis of the pottery body, in these two ancient sites comparison, the amount of alumina in the pottery body of Tepe Sadegh is slightly higher than in the samples of Shahr-i Sokhta. Therefore, in Tepe Sadegh, we encounter an increase of about 3.5% in the amount of alumina in the pottery body. The percentage and amount of alumina in the pottery body are directly related to the clay minerals in the pottery body. One of the effective factors is soil quality and processing of pottery, according to the results obtained in the samples of buff ware analyzed in Tepe Sadegh. The amount of this compound is more and higher than the amount of aluminum in the samples of buff ware discovered from Shahr-i Sokhta. This shows that the quality of pottery in this area has improved somewhat compared to the colored buff ware of Shahr-i Sokhta. Examination of the number of important impurities in the body of pottery, such as sulfur, manganese, and chlorine, also indicates that the amount of impurities in the body of colored buff ware, in the samples obtained from Tepe Sadegh in comparison with the buff ware of Shahr-i Sokhta, has been reduced to some extent. Conversely, the amount of main and important compounds

influencing the formation of the crystal structure of pottery has increased in Tepe Sadegh buff ware, which has caused the quality of buff ware in Tepe Sadegh compared to similar pottery of Shahr-i Sokhta to improve a little.

V. Conclusion

Experimental and structure studies of the chemical composition of the elements forming the body of buff ware in the Tepe Sadegh satellite area in comparison with similar pottery samples discovered from Shahr-i Sokhta from the Bronze Age were done. Different laboratory methods, such as X-ray diffraction (XRD) and X-ray fluorescence (XRF) in comparative comparison with each other, indicate that due to the great similarity due to the presence of the same crystalline phases in the body of buff ware in both areas. The chemical composition is relatively the same as the results of elemental analysis of the body of both pottery groups. In both archeological sites, natural and native clay mines and deposits of the region, which were probably the same and close to each other, were used to supply the soil used to make colored buff ware. On the other hand, there are slight differences in the composition of the body and the type of minerals formed in the body of the two groups of buff ware obtained from these two areas. It has been shown that the body of buff ware obtained from Tepe Sadegh has probably been slightly changed in terms of processing, firing, use of raw materials, and additives for making pottery products, in comparison with Shahr-i Sokhta pottery.

As a result, the quality of pottery products in this area has slightly improved. Therefore, it seems that according to the results of laboratory studies performed on the body of the samples of buff ware studied in these two ancient sites, by establishing specialized centers for the production of pottery products in the satellite areas of Shahr-i Sokhta, such as Tepe Sadegh, the quality of these products has also slightly enhanced due to the more specialized pottery profession in these satellite villages compared to Shahr-i Sokhta. Of course, it is clear that a definite statement on this issue requires further laboratory studies.

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