THE COMPOSITIONAL ANALYSIS OF MINERAL CONTENT AND GEO-CHEMISTRY OF THE ANCIENT GREY POTSHERDS FROM SHAHR-I SOKHTA, EAST OF IRAN

HOSSEIN MORADI
HOSSEIN SARHADDI-DADIAN
ZULISKANDAR RAMLI

ABSTRACT:

This study aimed to determine whether grey pottery shards from Shahr-I Sokhta were locally made or imported. Shahr-I Sokhta is one of the biggest ancient sites of Iranian civilization in southwest Asia, which is located in the Sistan Region, East of Iran, and its area is about 270 hectares. The site has been registered as a UNESCO World Heritage in 2014. Archaeologists believe that most of the pottery shards are locally made; hence, to test this hypothesis, a scientific analysis was done to determine the chemical composition of the pottery shards. X-Rays Fluorescence (XRF) was applied to determine the major and trace elements of the pottery shards while The X-Ray Diffraction (XRD) was employed to characterise and compare the mineral phases. The results demonstrate that most of the pottery shards are in the same group, and this strongly suggests that they are local products. Based on minerals existing in the pottery shard, it is indicated that the pottery shards were baked at very high temperatures. The high concentration of copper in the pottery shards shows that the pottery was glazed with a mixture of copper oxide. Copper oxide was added as colouring agents in the glazed mixture, giving a grey colour to the surface of the vessels. The concentration of lead is normal and minimal; usually lead is added as a colouring agent into the pottery. The ancient potters in Indus Valley always used lead as a colourant.

REZUMAT: ANALIZA COMPOZIŢIONALĂ A CONŢINUTULUI MINERAL ŞI A GEO-CHIMIEI FRAGMENTELOR DE CERAMICĂ CENUŞIE ANTICĂ DE LA SHAHR-I SOKHTA, ÎN ESTUL IRANULUI

Scopul acestui studiu a fost să stabilească dacă fragmentele de ceramică cenușie de la Shahr-I Sokhta au fost produse local sau au fost importate. Shahr-I Sokhta, una dintre cele mai vaste așezări ale civilizației antice iraniene din Asia de Sud-Vest, se situează în regiunea Sistan, în estul Iranului, și acoperă aproximativ 270 de hectare. Situl a fost înscris pe lista patrimoniului mondial UNESCO în 2014. Arheologii presupun că majoritatea fragmentelor ceramice sunt de producție locală; pentru a verifica această ipoteză, s-a efectuat o analiză științifică a compoziției chimice a fragmentelor. Prin fluorescență cu raze X (XRF) s-au determinat elementele majore și urmă, iar difracția cu raze X (XRD) a fost utilizată pentru caracterizarea și compararea fazelor minerale.

Rezultatele arată că majoritatea fragmentelor aparțin aceluiași grup, sugerând cu tărie proveniența locală. Prezența anumitor minerale indică faptul că piesele au fost arse la temperaturi foarte ridicate. Concentrația ridicată de cupru relevă faptul că suprafețele au fost glazurate cu un amestec pe bază de oxid de cupru, utilizat ca agent colorant pentru a obține nuanța cenușie. Nivelul de plumb este normal și minim, plumbul fiind adesea folosit drept colorant în antichitate; meșterii din Valea Indusului recurgeau frecvent la acesta în procesul de glazurare.

KEYWORDS: Shahr-I Sokhta, grey pottery, X-Rays Fluorescence (XRF), The X-Ray Diffraction (XRD), Iran

CUVINTE CHEIE: Shahr-I Sokhta, ceramică cenușie, fluorescență cu raze X (XRF), difracție cu raze X (XRD), Iran

Introduction

During the late Chalcolithic period (3300 BC to the mid-3rd millennium BC), evidence suggests the existence of long-distance exchanges of luxury goods. Notably, this includes the production of grey pottery in regions such as Makran, central and northern Pakistan, the Hirmand basin, the Iranian Baluchestan and Kerman areas. Grey pottery was initially reported first by Stein, from Shahi Tump in the Kech Valley of Pakistani Makran.[1]

[1] Stein 1931, 93.

Coinciding with the late Bronze Age (3500-3000 BC), an early form of grey pottery has been reported from areas of Pakistan and Afghanistan, known as Faiz Mohammad pottery.[2] At the beginning of the 3rd millennium BC, the Amir (Emri) type of grey pottery emerged. This variety, characterized by black or reddish paint on a grey background, was prevalent in eastern Iran and Baluchestan.[3] This type of pottery is widely distributed across the southeastern Iranian Plateau, especially in Sistan, Baluchestan, Pakistani Makran, Kerman, and the southern Persian Gulf regions in the UAE and Oman peninsula that is likely an evolved form of the Faiz Mohammad pottery. Additionally, a substantial collection of this pottery has been discovered in some areas of Japan in the Far East, referred to as South Pakistani pottery.[4] The grey vessels were produced at temperatures between 650 to 900 degrees Celsius. Exceeding 920 degrees Celsius would cause the vessels to exfoliate and lose their original form, and temperatures above 1100 degrees Celsius would result in vitrification of their surfaces.[5]

Decorated grey pottery has been reported in southeastern Iran, including the graveyards of Khurab, Damin, and Bampur, as well as in the graveyards of southeastern Iran and Pakistani Baluchestan.[6] Among the two known types of grey pottery, Amir and Faiz Mohammad, the former was more prevalent in southeastern Iran and southwestern Pakistani Baluchestan. In contrast, the distribution of the latter was almost exclusive to northern Pakistan and was found alongside the Amir type at only four other major sites in Iran and Pakistan.[7]

The Amir type pottery commonly features motifs such as the four-winged swastika, prevalent at numerous sites in southeastern Iran, with the earliest instances dating back to around 3000 BC. Animal motifs, notably the Baluchi ibex, are also prominent decorations on these vessels. Additionally, geometric patterns like parallel bands and square zig zags have been identified on this pottery.[8] At the Bampur in Iranian Baluchestan, Amir grey pottery is categorized into two types: painted and incised. These vessels are typically wheel-made, with many pieces adorned with various motifs including appliqué, painted designs, or combed/incised patterns. The pottery is characterized by a compact, well-fired fabric ranging from light to dark grey, often categorized as fine grey ware. These vessels lack a slip and feature decorations in black, dark brown, or glossy black.[9] Similar characteristics are observed in the Amir type pottery found in southwestern Pakistani Baluchestan compared to its Iranian counterparts.

As previously mentioned, the widespread distribution of this pottery across southeastern Iran has led to various hypotheses regarding its origins. The most significant of these hypotheses involves investigating the primary origin of its production. Some researchers propose that this pottery was exported from specific areas in southeastern Iran to other sites, suggesting it was traded as a commodity.

Shahr-I Sukhta, the Problem of the Grey Wares. Methodology and Sampling

Shahr-I Sukhta is situated 56 kilometres from Zabol, in Sistan and Baluchestan province, along the Zabol-Zahedan Road (see Fig. 1). The initial settlement in this city dates back to 3200 BC, spanning four cultural periods, between 3200 and 1800 BC. Shahr-i Sukhta was initially excavated by Italian archaeologists under the leadership of Maurizio Tosi, between 1968 and 1978.[10] Following a hiatus, an Iranian archaeological team led by Seyyed Mansour Seyyed Sajjadi has conducted excavations at various parts of the site since 1997.[11] Shahr-i Sukhta is one of the largest Bronze Age sites on the Iranian plateau, covering an area of over 200 hectares. The urban area spans approximately 120 hectares, while the cemetery area, located to the south of the residential section, covers about 20 hectares. Excavation results indicate four cultural and settlement periods (I-IV) in this city, divided into ten phases. Period I spans from approximately 3200 to 2800 BC, Period II from 2800 to 2500 BC, Period III ranges from 2300 to 2500 BC, and Period IV is proposed to have occurred between 2000 and 2200 BC. Excavations conducted across various parts of the city reveal that it comprised five sections: the eastern residential area, the central residential section, an industrial area, the area of monumental buildings or northern residential section, and the cemetery. These sections are situated as consecutive and adjoining mounds.[12]

The predominant pottery from the Shahr-i Sukhta is characterized by a buff-coloured paste, although variations extend from buff to brick-red and even greenish hues. Grey pottery, a secondary type also produced in Shahr-i

2 Fairservis 1961, 86.
3 Wright 1984, 137.
4 Konasukawa et al. 2011; Sajjadi 2018, 85.
5 Sajjadi 2018, 89.
6 Stein 1931, 93.
7 Sajjadi 2022, 287.
8 Sajjadi 2022, 292.
9 De Cardi 1970, 319.
10 Tosi, 1983; Salvatori and Vidale, 1977.
11 Sajjadi, 2014.
12 Mariani 1992.

Sukhta workshops, is mostly unearthed from excavations in the cemetery. Red pottery, ranking third in production, is relatively scarce. Both buff and grey pottery from the Burnt City feature diverse decorations, including geometric patterns such as simple lines, stripes, hollow and filled triangles, parallel lines, filled diamonds or rectangles, squares, and inverted triangles.[13] These artifacts have been discovered in both residential areas and excavated graves within the Shahr-i Sukhta cemetery.[14]

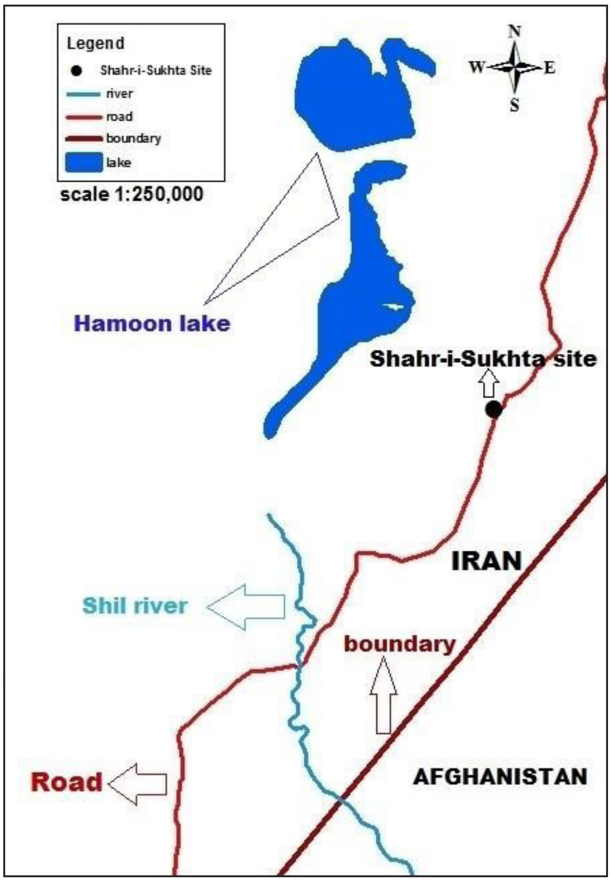

Fig. 1 Location of the site in Eastern Iran.

This type of pottery from Shahr-i Sukhta in Sistan has also been discovered in abundance approximately 400 kilometres north of Bampur. The pottery was manufactured in neighbouring sites, towns, and villages such as Tepe Dasht, situated three kilometres southwest of the city, and in the Rud Biaban mounds, located 25 kilometres south of the city. These locations are notable examples of pottery-making centres during the third millennium BC[15]. Following buff pottery, grey pottery is the next most abundant type found at Shahr-e Sukhteh. Grey pottery has been unearthed in layers ten to four of the Shahr-i Sukhta(3200-2300 BC), and one notable characteristic of Shahr-i Sukhta pottery is its simplicity. The black-on-grey painted vessels from Shahr-i Sukh exhibit a contemporary style found in southeastern Iran and Pakistan, particularly in the Kech plain of western Pakistani Baluchestan and sites on the Arabian Peninsula, notably Oman. This type of pottery is also present at Tepe Yahya and Bampur. In terms of form and decoration, this pottery bears similarities to examples from Bampur I-IV, Shahdad, Yahya IVC-B, and to some extent Mundigak IV.[16] This category of pottery, along with examples from neighbouring regions, particularly Pakistani Baluchestan, has been extensively discussed in various publications by Rita Wright.[17] Recent studies on Shahr-i Sukhta pottery suggest the prevalence of a distinct new type of grey pottery exclusive to the site, absent in other regions.[18] The evidence and documentation necessary to establish pottery connections between southeastern Iran and Pakistani Baluchestan during the late fourth and early third millennia, particularly in the early settlement periods of the Shahr-e Sukhteh, rely on certain types found in the royal cemetery of Shahi Tump and Miri Qalat in Pakistani Makran. Additionally, the presence of the Amir 2 pottery type in the Arabian Peninsula, with its limited occurrence in phases 7 to 4 or 3 of the Shahr-e Sukhteh, provides valuable clues for tracing and identifying potential connections between this city and other sites around the Persian Gulf. These findings can also assist in dating the graves of Khurab and Shahi Tump.[19]

According to Wright, the Faiz Mohammad pottery discovered at Shahr-i Sukhtawas imported from central Baluchestan and sites located between Baluchestan and the Iranian plateau, indicating extensive trade connections with distant regions.[20] This shallow pottery type, contemporaneous with Mehrgereh phases V-VII and Damb Sadaat phases II-III, has been recovered from Periods III-IV at Shahr-i Sukhta.[21] Meanwhile, the Amir pottery from Shahr-i Sukhtaphases I-III corresponds in time with Bampur phases IV-V and Yahya phases IVC-B.[22]

13 Biscione and Bulgarelli, 1983.
14 Sajjadi 2022.
15 Moradi et al, 2013.
16 Sajjadi 2018.
17 Wright 1984.
18 Sajjadi 2018, 89.
19 Wright 1984, 147.
20 Wright 1984, 147.
21 Sajjadi 2003.
22 Sajjadi 2018, 115.

In a previous elemental and chemical study conducted by the authors on 15 samples of buff and grey pottery from Shahr-e Sukhteh, it was found that the elemental composition of two grey pottery samples in this collection differed from the buff samples and showed greater similarity to or derivation from areas in Pakistani Baluchestan and the Indus Valley.[23]. This finding somewhat substantiates the hypothesis that this pottery was involved in trade exchanges. Subsequently, through a detailed study of the external characteristics of grey pottery collected over more than 20 excavation seasons at Shahr-i Sukhta from 1997 to 2022, it was determined that these pottery items can be classified into two categories based on external texture and paste: fine and coarse. The fine samples exhibited textures and designs closely resembling the Amir grey pottery found across various regions of Baluchestan and Kerman, notably Bampur and Tepe Yahya. In contrast, the coarse samples displayed similar designs but had a more loose and flaky texture, suggesting that these items may have been locally produced at Shahr-e Sukhteh. Building upon previous studies, additional samples were analysed to further investigate whether grey pottery from Shahr-i Sukhta played a role in trade exchanges. This ongoing research aims to refine our understanding and evaluate hypotheses regarding the origin and distribution of this pottery type.

All samples examined in this article were systematically collected from the eastern residential section, specifically from square X.

Materials and Methods

The X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) methods were employed in this study to characterise and compare the mineral phases and elemental contents of the earthenware. In pottery studies, XRD and XRF techniques have been widely exploited by archaeologists in verifying ancient origins and technology of pottery[24], beads[25] and ancient bricks.[26] XRD provides information on the actual minerals present in the sample, while XRF renders information on the major and trace elements of any materials studied.

A total of 20 grey coloured pottery shard samples from Shahr-I Sokhta, South Eastern Iran were taken to the lab for cleaning, and were labelled with the names SS1, SS2, SS3, SS4, SS5, SS6, SS7, SS8, SS9, SS10, SS11, SS12, SS13, SS14, SS15, SS16, SS17, SS18, SS19, and SS20 (See Fig. 2).

The analysis was conducted to determine the mineral content and geo-chemistry of the ancient pottery samples. All the samples used in this study were digitally photographed before being crushed and pulverised to a homogenised grain size 20-30 µm using Retch PM100 milling machine. Samples, weighing 0.4 g, were refined and heated up for one hour at a temperature of 105^{o} C, and mixed until they turned homogenous with the flux powder, Spectroflux 110 (product of Johnson and Mathey). These mixtures were melted for one hour in a furnace at a temperature of 1100^{o} C. The homogeneous melt was then moulded in a container and cooled gradually into pieces of fused glass with the thickness of 2 mm and diameter of 32 mm. In result, the samples were ensured to have a ratio of 1:10 dilution. Samples in the form of fused glass were prepared to analyse major elements, such as Si, Na, K, Ca, Fe, Al, Ti, Mn, Mg and P_2O_5. This was then followed by the preparation of pressed pellet samples in order to analyse their trace elements, such as As, Ba, Ce, Cr, Cu, Ga, Ni, Pb, Rb, Sr, V, Zn, and Zr. For XRF, the Panalytical Axios Max was applied to analyse all the prepared samples. The applicability of the methods for the multielemental analysis by XRF of the pottery shards is evaluated using the analysis of certified reference materials (CRMs), 315 Fire Brick (Calibration: G-FBVac28 mm) for major elements and certified reference material, SY-2 (Calibration: Trace Element P-20) for trace elements. The CRMs were also used as the quality control materials of the analytical procedure. For XRD, the Bruker D8 Advance was used to analyse the samples with parameters; 40 kV, 40 mA, 2 theta range from 10°-70°, with Copper (Cu) X-Ray tube at 0.04/s scan rate. All diffractograms from the analysis were further analysed using the DIFFRAC.EVA version 3.0 software. Peaks and patterns were matched with qualitative Crystallography Open Database (COD). For XRF, the Panalytical Axios Max was used to analyse all the prepared samples.

Scatter plot diagrams of Al_2O_3 versus CaO, MgO versus TiO_2 and Sr versus Rb were then performed to demonstrate the differences among the groups and were analysed using Microsoft Excel software. The main purpose is to see the distribution of the samples in the group and subsequently to compare with the clay elements. Hierarchical Cluster Analysis (HCA) was applied to the chemical data from the four components, namely aluminium (Al_2O_3) and calcium (CaO), strontium and rubidium, of all 20 pottery shards samples in order to verify the presence of compositional groups of pottery shards differentiated by their probable major and trace element sources. The

23 Moradi et al., 2013; Saadatian and Roostaei 2023.

24 Ramli et al. 2011; Moradi et al. 2013; Malee and Thiansem 2016; Pourzarghan, Sarhaddi-Dadian and Ramli 2017; Sarhaddi-Dadian et al. 2017; Sarhaddi-Dadian 2021; Bater and Habil 2023; Bater et al. 2022.

25 Jusoh et al. 2012; Ramli et al. 2017; Rahman et al. 2019; Reinhard et al. 2020.

26 Ramli et al. 2013; Miri et al. 2020.

measurement of distance used in the assignment rule was based on Ward's Linkage and Squared Euclidean Distance algorithm. The results are presented in the form of a dendrogram (Figures 5 and 6) showing the distance between the pottery samples based on their TiO_2 and MgO concentration and strontium and rubidium concentration in the graphical form.

Fig. 2 The sample of potsherds from the Site.

Results and Discussion

The composition analysis on the pottery shard samples from Shahr-I Sokhta, Southeastern Iran was carried out to determine its geo-chemical and mineral contents. All the pottery shards were grey in colour. The composition analysis on the potsherds helped to determine if local raw material was used to produce these potteries. The mineral content in the pottery samples showed the presence of minerals, such as quartz, cristobalite, and labradorite, and the mineral contents of each sample is shown in Table 1. From the result and the XRD pattern, it is clear that the quartz was present in each sample (Fig. 3). Labradorite was present in samples SS6 and SS11 whilst samples SS1, SS2, SS4, SS5, SS16, SS17 and SS20 shows the existence of cristobalite mineral. Labradorite is a feldspar mineral of the plagioclase series that is most often found in mafic igneous rocks such as basalt, gabbro, and norite. It is also found in anorthosite, an igneous rock in which labradorite can be the most abundant mineral. Analysis do not show any clay mineral content in the pottery shards such as kaolinite or illite and it can be suggested that the shards were baked at a temperature more than

Table 1 Mineral contents in grey pottery shards unearthed from Shahr-I Sokhta, Southeastern Iran.

Sample	Mineral
SS1	SiO_2 Quartz; β-quartz: trapezohedral SiO_2 Cristobalite
SS2	SiO_2 Quartz; β-quartz: trapezohedral SiO_2 Cristobalite
SS3	SiO_2 Quartz
SS4	SiO_2 Quartz; β-quartz: trapezohedral SiO_2 Cristobalite
SS5	SiO_2 Quartz; β-quartz: trapezohedral SiO_2 Cristobalite
SS6	SiO_2 Quartz; $(Ca,Na)(Al,Si)_4O_8$ Labradorite
SS7	SiO_2 Quartz
SS8	SiO_2 Quartz
SS9	SiO_2 Quartz; β-quartz: trapezohedral SiO_2 Cristobalite
SS10	SiO_2 Quartz
SS11	SiO_2 Quartz; $(Ca,Na)(Al,Si)_4O_8$ Labradorite
SS12	SiO_2 Quartz
SS13	SiO_2 Quartz
SS14	SiO_2 Quartz
SS15	SiO_2 Quartz
SS16	SiO_2 Quartz; β-quartz: trapezohedral SiO_2 Cristobalite
SS17	SiO_2 Quartz; β-quartz: trapezohedral SiO_2 Cristobalite
SS18	SiO_2 Quartz
SS19	SiO_2 Quartz
SS20	SiO_2 Quartz; β-quartz: trapezohedral SiO_2 Cristobalite

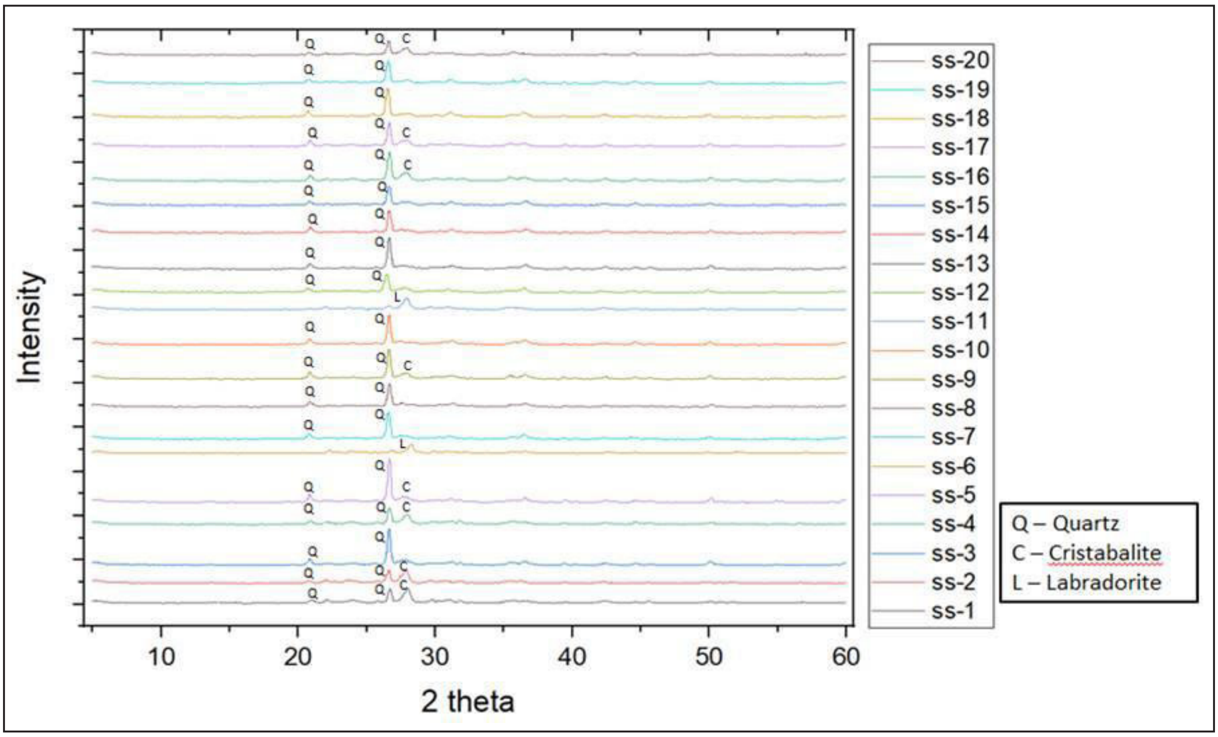

Fig. 3 XRD pattern of grey pottery shards from Shahr-I Sokhta, Southeastern Iran.

750°C. Based on cristobalite mineral existed in the pottery shard, it indicated that the pottery sherds were baked at very high temperature, which is more than 1450°C.

The contents of the major elements in the pottery fragments can be referred to in Table 2. The analysis shows that the pottery fragments contained 57.75 % to 65.05 % dry weight silica. The percentage of dry weight for aluminium elements is between 13.88 % and 16.75 %. While iron elements contain a dry weight percentage of 6.64 % to 8.93 %. Further to this, the percentage of dry weight for potassium elements ranged from 2.17 % to 3.13 %, while dry weight calcium ranged from 1.08 % to 6.01 %. The percentage of dry weight for titanium elements ranged from 0.05 % to 0.11 %, while dry weight for phosphorus ranged from 0.09 % to 0.23 %. The percentage of dry weight magnesium and sodium elements was 2.92 % to 4.78 % and 0.93 % to 2.65 %. Manganese elements contain a percentage of dry weight 0.72 to 0.96 % respectively. The percentage of P_2O_5 which is average in every shard

Table 2. Major elements of grey pottery shards from Shahr-I Sokhta, Southeastern Iran.

Sample	Dry Weight (%)										
	SiO_2	$A1_2O_3$	Fe_2O_3	CaO	Na_2O	MgO	K_2O	MnO	TiO_2	P_2O_5	LOI
SS1	61.98	14.82	6.64	5.05	2.00	3.22	2.65	0.73	0.08	0.10	0.72
SS2	61.32	14.76	7.58	5.30	1.92	3.16	2.63	0.72	0.09	0.22	0.53
SS3	61.54	15.84	7.78	2.81	1.63	4.33	2.72	0.78	0.10	0.15	1.27
SS4	59.26	15.97	8.01	4.52	2.65	3.68	2.60	0.75	0.10	0.13	0.54
SS5	63.18	16.02	7.66	1.09	2.30	3.37	2.68	0.84	0.05	0.09	1.41
SS6	61.88	14.29	8.93	4.99	0.93	3.52	2.79	0.73	0.11	0.09	0.01
SS7	65.05	14.87	8.26	1.60	1.06	3.83	2.81	0.80	0.07	0.11	0.99
SS8	63.53	15.99	8.65	1.14	1.02	4.55	3.09	0.95	0.06	0.11	0.62
SS9	61.31	15.47	7.02	3.63	1.40	4.05	2.71	0.74	0.07	0.15	2.18
SS10	61.81	16.75	8.47	1.08	1.04	4.78	3.13	0.96	0.06	0.11	0.58
SS11	60.91	14.06	7.89	6.01	0.98	3.62	2.39	0.69	0.11	0.11	1.57
SS12	64.15	14.09	7.18	3.07	1.25	3.13	2.72	0.75	0.06	0.10	1.83
SS13	64.30	14.46	7.32	2.03	1.60	3.78	2.86	0.78	0.07	0.15	1.90
SS14	63.99	14.68	6.82	2.48	1.28	3.39	2.92	0.77	0.06	0.10	1.55
SS15	62.46	14.55	8.57	2.16	1.39	3.44	2.60	0.86	0.08	0.13	1.83
SS16	58.49	15.70	8.30	4.89	2.07	3.61	2.41	0.76	0.11	0.23	1.64
SS17	59.98	14.96	7.62	4.76	1.49	3.55	2.81	0.74	0.06	0.15	2.52
SS18	60.14	13.88	8.44	3.72	1.26	4.65	2.17	0.74	0.07	0.12	1.81
SS19	64.22	14.80	8.82	1.90	1.00	3.57	2.80	0.84	0.07	0.12	1.76
SS20	57.75	13.91	7.54	5.60	1.27	2.92	2.91	0.68	0.08	0.12	6.05

indicates that none of these vessels have been used as a cookpot. The high content of P_2O_5 is an indicator of organic materials existing in the potteries. Fig. 4 shows the scatter plot graph for percentage of dry weight of Al_2O_3 and CaO elements of grey pottery shard samples unearthed in Shahr-I Sokhta, Southeastern Iran. Based on the scatter plot graph, it can be suggested that grey pottery sherds samples from Shahr-I Sokhta, Southeastern Iran can be divided into more than two groups. Fig. 5 shows the scatter plot graph for percentage of dry weight of MgO and TiO_2 elements of the grey pottery samples Shahr-I Sokhta, Southeastern Iran. Based on the scatter plot graph, it can be suggested that grey pottery sherds samples from Shahr-I Sokhta, Southeastern Iran can be divided into more than one group. Based on Fig. 4 and Fig. 5, it shows that the raw materials of the clay used by the local potters were taken from several locations. Hierarchical agglomerative clustering of the Al_2O_3 and CaO concentration shows that there are four components of clusters based on the significance value of cluster distance of 10 (Fig. 7). The result of Hierarchical Agglomerative Clustering is parallel with scatter plot graphs which shows there are more than one

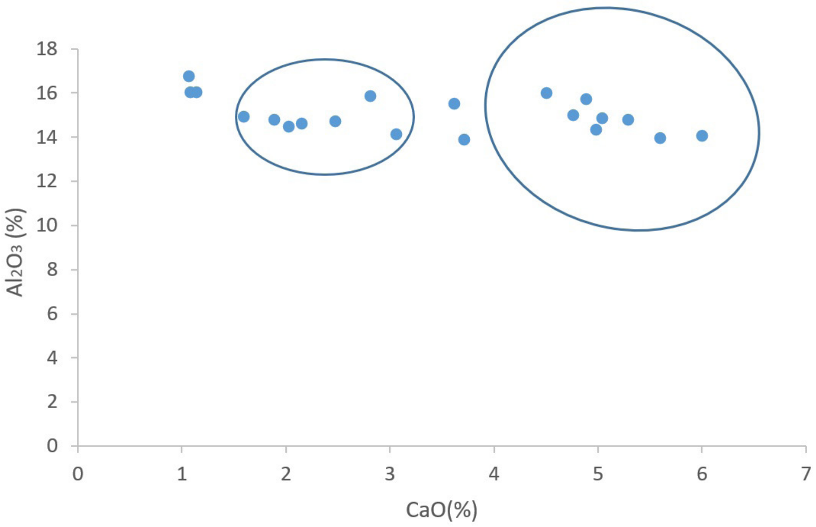

Fig. 4 Scatter plot - the scatter plot of CaO versus Al2O3.

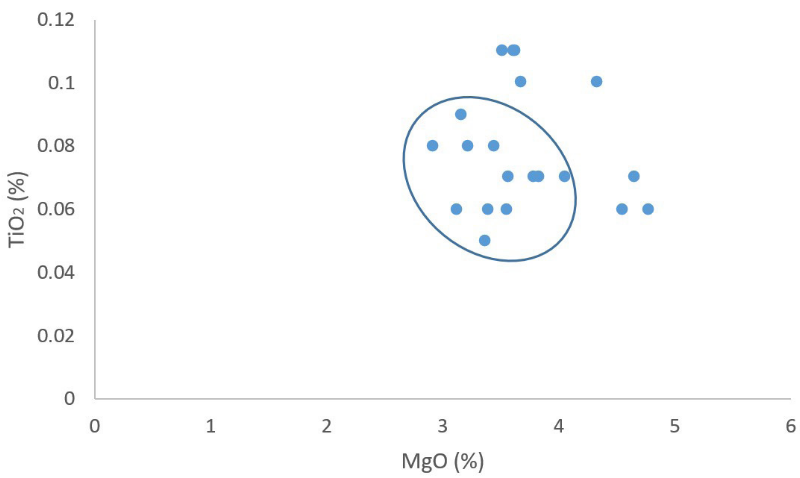

Fig. 5 Scatter plot - the scatter plot of MgO versus TiO2.

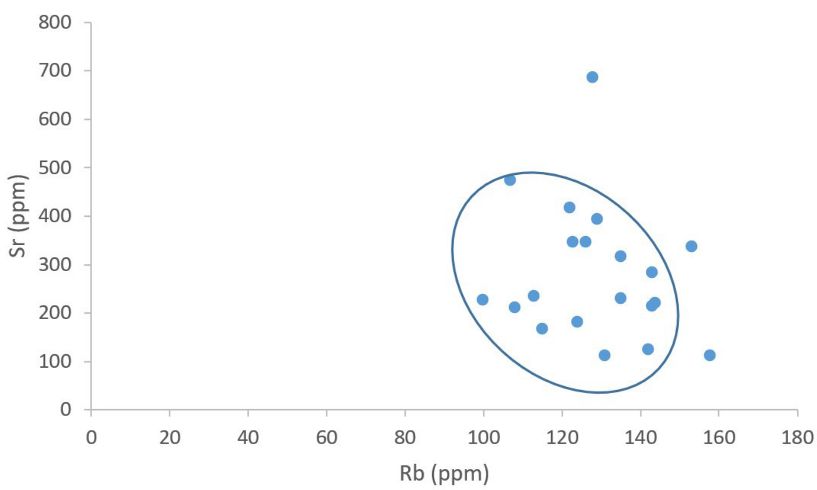

Fig. 6 Scatter plot - the scatter plot of Rb versus Sr.

sources of raw materials used for making grey potteries in Shahr-I Sokhta, Southeastern Iran. The content of the trace elements is shown in Table 3. The result shows that most of the pottery samples have a high concentration of copper which range of the concentration is from 237 ppm to 4496 ppm. The high concentration of copper in the pottery shards shows that the pottery was glazed with a mixture of copper oxide. Copper oxide was added as colouring agents in the glazed mixture giving a grey colour to the surface of the pottery. The concentration of lead is from the range of 42 ppm to 243 ppm. The concentration of lead is normal and minimal and usually lead is added as a colouring agent into the pottery and the ancient potters in Indus Valley always used lead as a colourant.[27] Fig. 6 shows the scatter plot of strontium versus rubidium; it shows that some of the shards are not local but many of the shards belong to one group which is suggested as local production pottery. Hierarchical agglomerative clustering of strontium and rubidium concentration shows that there are also two components which are group A and group B. Most of the samples are in group A which is considered as local production whilst group B is considered as an anomaly because of compositional difference (Fig. 8). Hierarchical agglomerative clustering of strontium and rubidium concentration show a different result compared to the hierarchical agglomerative clustering of Al_2O_3 and CaO concentration, but we strongly suggest that sample SS15 was just an anomaly because of differences in compositional contents.

27 Caleb 1991.

Table 3 Trace elements of grey pottery shards from Shahr-I Sokhta, Southeastern Iran.

Sample	Concentration (ppm)												
	Ba	Ce	Co	Cr	Cu	Ni	Pb	Rb	Sr	V	Y	Zr	Zn
SS1	254	85	16	156	596	83	110	100	226	77	50	136	624
SS2	345	1	22	118	1231	89	132	129	393	93	52	210	884
SS3	422	84	21	151	862	167	115	135	228	96	55	219	659
SS4	341	1	22	99	1048	99	108	126	345	96	49	193	787
SS5	429	73	19	199	756	136	102	113	235	97	53	197	658
SS6	257	45	23	124	2410	175	154	135	314	99	51	204	1585
SS7	155	56	23	131	237	155	42	158	113	98	59	236	302
SS8	194	97	21	187	694	188	73	142	125	103	55	197	643
SS9	215	92	19	123	579	148	74	124	182	86	54	176	572
SS10	227	10	25	188	1228	200	104	131	111	105	60	198	957
SS11	511	57	20	126	1553	145	110	107	473	90	46	177	1169
SS12	217	74	18	113	2766	139	175	144	220	88	53	200	1805
SS13	239	92	21	123	3585	162	242	115	166	88	45	158	2270
SS14	294	45	21	119	2116	149	141	108	210	83	49	150	1504
SS15	670	37	23	187	3024	207	180	128	686	101	50	229	1963
SS16	334	54	22	142	879	177	100	143	282	101	54	233	621
SS17	367	31	20	106	1466	134	116	153	335	93	57	231	949
SS18	317	18	27	178	4496	304	243	123	346	95	45	223	2715
SS19	408	17	27	148	2473	210	175	143	214	104	49	212	1626
SS20	242	25	17	78	1120	88	81	122	418	82	48	211	781

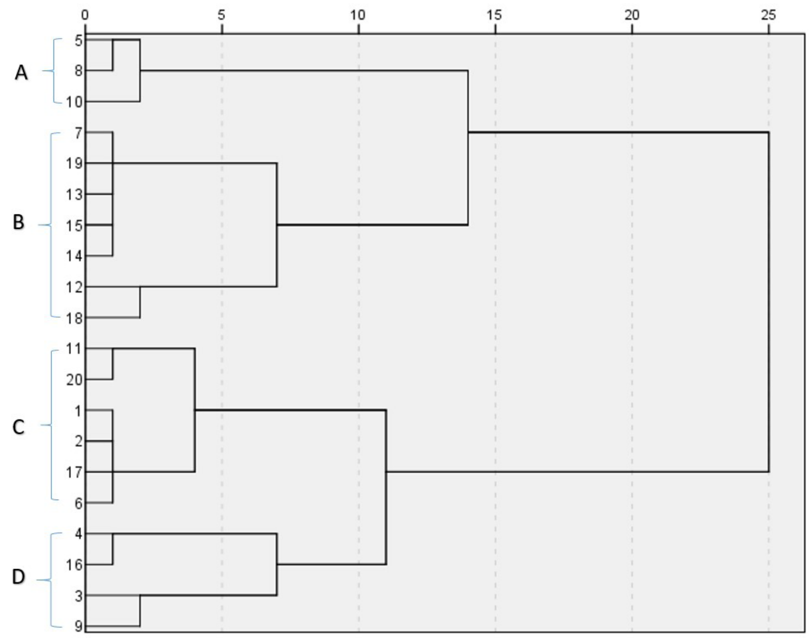

Fig. 7 Hierarchical agglomerative clustering of the Al_2O_3 and CaO concentration of the pottery shards from Shahr-I Sokhta.

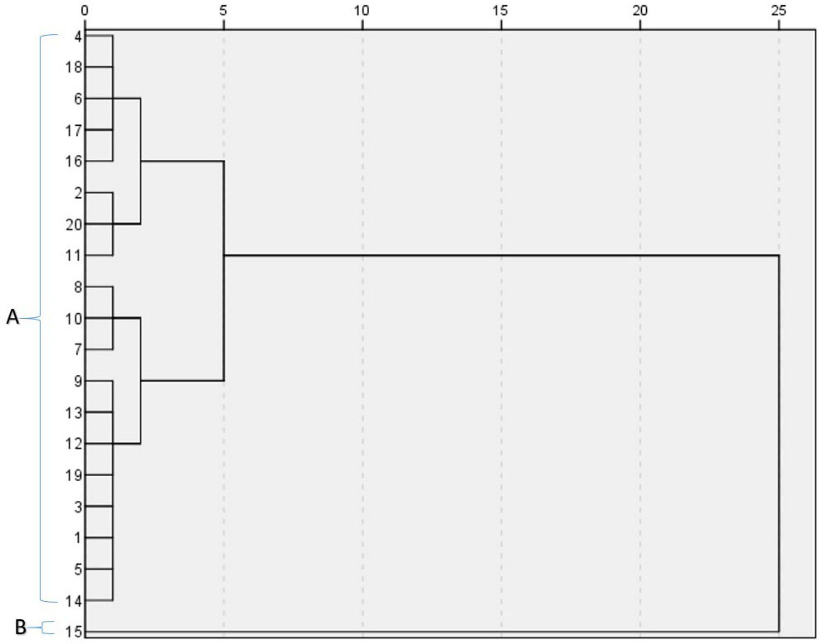

Fig. 8 Hierarchical agglomerative clustering of the Rb and Sr concentration of the pottery shards from Shahr-I Sokhta.

Conclusion

The compositional analysis showed that most of the pottery shards taken from Shahr-I-Sokhta's archaeological site are locally made. Grey pottery shards of Shahr-I Sokhta contain minerals such as quartz, cristobalite and labradorite. Based on the minerals found in the pottery shards, it was inferred that they were baked at very high temperatures. The high concentration of copper in the pottery shards shows that the pottery was glazed with a mixture of copper oxide. Copper oxide was added as colouring agents in the glazed mixture and gives a grey colour to the surface. It seems plausible to suggest that the technique originated in the Indus Valley and was subsequently diffused into the region. This hypothesis, however, requires further investigation through comprehensive research.

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References

Bater, M. and Habil, A. 2023. Structural and Laboratory Study of a Few Grey Painted Potteries from Shahr-I Sokhta. Journal of Sistan and Baluchistan Studies, 2(2): 77-84. doi: 10.22034/jsbs.2022.337776.1022

Bater, M., Shirazi, R., Barkhordar, H. and Barani, R. 2022. 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. Journal of Sistan and Baluchistan Studies, 2(1): 19-27. doi: 10.22034/jsbs.2022.337229.1019

Biscione, R. 1974. Relative Chronology and Pottery Connections Between Shahr-I Sokhta and Mundigak, Eastern Iran. Memorie Dell'istituto Italiano Di Paleontologia Umana, 2: 131-145.

Caleb, H. 1991. Construction materials: Type, uses and application. The Geological Society of America, New York.

Fairservis, W.A. 1961. Archaeological studies in the Seistan basin of Southwestern Afghanistan and Eastern Iran. Anthropological Papers of the American Museum of Natural History, Vol. 48(1). New York: American Museum of Natural History.

Jusoh, A., Sauman, Y., Rahman, N.H.S.N Amp; Ramli, Z. 2012. Scientific Analysis of Samples of Some Artefacts Metals Age in Malaysia. Social Sciences (Pakistan), 7(6): 772-777.

Konasukawa, A., Shudai, H., Kimura, S., Ueno, T. and Endō, H. 2011. Report on the Survey of the Archaeological Materials of Prehistoric Pakistan stored in Aichi Prefectural Ceramic Museum. Part 3: Emir Ware and Quetta Style pottery. The Bulletin of Tsurumi University: Studies in Humanities, Social and Natural Sciences, 48(4), pp.73-110.

Malee, U. and Thiansem, S. 2016. Analytical Study of Ancient Pottery from the Archaeological Site of Ban Bo Suak from Nan Province, Thailand. Key Engineering Materials, 690, 18–22.

Mariani, L. 1992. The Eastern Residential Area at Shahr-i Sokhta. In C. Jarrige (ed.), South Asian Archaeology 1989, Paris, 181-193.

Miri, N.K., Sarhaddi-Dadian, H., Bahramzadeh, K. and Hashemi-Baghi, M. 2020. Comparison of Vulnerability Conditions of Adobes' Structure–The Study of Historical and Restored Adobes of Kooh-E Khajeh Ancient Site (Kohan Dezh Castle) in Sistan. Iran, Materiale și Cercetări Arheologice, 15: 267-278.

Moradi, H., Hossein Sarhaddi Dadian, Ramli, Z., and Rahman, N.H.S.N.A. 2013. Compositional Analysis of The Pottery Shards of Shahr-I Sokhta, South Eastern Iran. Research Journal of Applied Sciences, Engineering and Technology, 6(4): 654–659.

Pourzarghan, V., Sarhaddi-Dadian, H., and Ramli, Z. 2017. Morphology of Ancient Potteries Using X-Ray Diffraction Analysis and X-Ray Fluorescence in Sistan Plain, Eastern Iran. Mediterranean Archaeology & Archaeometry 17(2): 175-186.

Rahman, N.Q.A., Ramli, Z., Hussin, A., Nasir, M.N.M., Supian, N.S.M., and Sarhaddi-Dadian, H. 2019. Elemental Analysis by Field-Emission Scanning Electron Microscope of Ancient Glass Beads Sample from Pulau Kalumpang Archaeological Site, (Perak, Malaysia). Mediterranean Archaeology & Archaeometry 19(1): 91-105.

Ramli, Z., Rahman, N.H.S.N.A., Jusoh, A., and Sauman, Y. 2011. X-Ray Diffraction and X-Ray Fluorescent Analyses of Prehistoric Pottery Shards from Ulu Kelantan. American Journal of Applied Sciences, 8(12): 1337–1342.

Ramli, Z., Rahman, N.Q.A., Hussin, A., Hasan, S.N.I.S. and Dali. A.M. 2017. Compositional Analysis of Sungai Mas, Kuala Selinsing and Santubong Glass Beads. Mediterranean Archaeology and Archaeometry, 17(2): 117-129.

Ramli, Z., Rahman, N.H.S.N.A., Samian, A.L., and Yarmo, M.A. 2013. X-Ray Diffraction and X-Ray Fluorescence of Ancient Bricks of Candi Bukit Pendiat (Site 17), Bujang Valley, Kedah. Research Journal of Applied Sciences, Engineering and Technology, 6(6): 1094–1100.

Saadatian, M. and Roostaei, M.S. 2023. Archaeological Survey of the Zahedan-Zabol Gas Transmission Route. *Journal of Sistan and Baluchistan Studies*, *3*(2):1-14. doi: 10.22034/jsbs.2022.342620.1029

Salvatori, S. and Vidale, M. 1997. Shahr-i Sokhta, 1975-1978: Central Quarters Excavations: Preliminary Report. Instituto Italiano per l'Africa e l'Oriente.

Sarhaddi-Dadian, H., Moradi, H., Ramli, Z. and Purzarghan, V. 2017. X-Ray Fluorescence Analysis of The Pottery Shards from Dahan-E Ghulaman, The Achaemenid Site in Sistan, East of Iran. Interdisciplinaria Archaeologica, 8(1): 35–42.

Sarhaddi-Dadian, H., Ramli, Z. Moradi, H. and Jozi, Z. 2021. Compositional Analysis of The Pottery Shards from Kuh-I Khawja Historical Site, Sistan, East of Iran. Journal of Ancient History and Archaeology 8(1): 127-133

Sarhaddi-Dadian, H. 2021. Intercultural Relationships in South-East of Iran During the Late 4th and3rd Millennium BC: Tepe Keshari as A Key Site in Baluchestan Region. Studii De Preistorie, (18):147-160.

Sajjadi S.M.S. 2022. The Emir Ware from Shahr-i Sokhta. In Excavations and Researches at Shahr-i Sokhta 3. Pishin Pajouh. Iran

Sajjadi, S.M.S. 2018. The Proud Cultural Heritage of Iran 5. Thanks to the Efforts of Ahmad Mohit Tabatabai and Shahin Aryamnesh. Tehran, Research Institute of Cultural Heritage, Handicrafts and Tourism - Aryarmena Publications and Tissafern Archaeological Research Group: 81-136.

Sajjadi, S.M.S. 2003. Excavations at Shahr-i Sokhta. First Preliminary Report of the Graveyard. 1997-2000. Iran 41: 21-97.

Sajjadi, S.M.S. 2014. Some Preliminary Observations from the New Excavations at the Graveyard of Shahr-i Sokhta. In C.C. Lamberg-Karlovsky, B. Genito and B. Cerasetti (eds.), My Life is like the Summer Rose. Maurizio Tosi e l'archeologia come modo di vivere: Papers in Honours of Maurizio Tosi for His 70th Birthday, Oxford, 665-676.

Stein, M.A. 1931. An archaeological tour to Gedrosia: a detailed report on the extended investigation into the important but little known region of Gedrosia comprising the territories of Kharan, Makran and Jhalawan. Vancouver.

Tosi, M. 1983. Excavations At Shahr-I Sokhta 1969–1970. Prehistoric Sistan, 1: 73-125.

Wright, R.P. 1984. Technology, Style and Craft Specialization: Spheres of Interaction and Exchange in the Indo-Iranian Borderlands, Third Millennium BCE (Ph.D. dissertation) Department of Anthropology, Harvard University.

Lista ilustrațiilor

HOSSEIN MORADI
independent researcher, Iran
h_moradi@yahoo.com

HOSSEIN SARHADDI-DADIAN
Department of Archaeology, Faculty of Art and Architecture,
University of Zabol, Iran
hsarhaddi@uoz.ac.ir

ZULISKANDAR RAMLI
Laboratory of Archaeology and Archaeometry, Institute of the Malay World and Civilization,
University Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
ziskandar@ukm.edu.my