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Research Article

Compositional Analysis of the Pottery Shards of Shahr-I Sokhta, South Eastern Iran

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Abstract: The aim of this study is to determine whether pottery shards from Shah-I Sokhta especially the shards with red and gray in color are locally made or imported from elsewhere. Shah-I Sokhta is one of the most ancient settlement in Iranian Sistan and has been occupied by human since more than 5000 years ago. Based on archaeological excavations, the most ancient layer, considered as Period I, shows southern Turkmenian influences evidenced by clay figurines and pottery vessels similar to those of Namazga III period. The second period of occupation is dated between 2800 and 2500 BC. The first half of period III, ca. 2500-2200 BC, seems to be an continuation of the social changes of period II, but during the second part of period III signs of social/economical decline and environmental changes began to appear, leading to a great reduction of surface of the site in period IV (2200-1800 BC). By the end of period IV Shahr-I Sokhta was completely abandoned. Archaeological excavations also unearth thousand of pottery shards which are buff, grey and red in color which are mostly shards from broken bowls, jars, beakers and dishes. Archaeologists believe that most of the buff pottery shards are locally made; hence to determine whether this hypothesis is true, a scientific analysis was done to determine the chemical compositions of the pottery shards. The technique involved X-Rays Fluorescence (XRF) equipment which was applied to determine the major and trace elements of the pottery shards. The results shows that most of the pottery shards are in the same group and this strongly suggest that they are local products. Additionally, based on the major and trace elements, it can be suggested that sample 18259-9, 18265-10, 18266-13, 18271-15 and 18273-4 are not locally made and the surface of these potteries are buff and red in color.

Keywords: Archaeometry, namazga III, pottery, shah-i sokhta, X-Rays Fluorescence (XRF)

INTRODUCTION

Shahr-I Sokhta (the Burnt City) is located in the South Eastern part of Iran, *ca.* 57 km south of Zabol, the capital of the district (Fig. 1). In the early decades of the last century, Sir Aurel Stein provided the first archaeological information about this site; later on, between 1967 and 1978, it underwent extensive excavations and research by the Italian archaeological expedition of the IsMEO, headed by Piperno and Tosi (1975), Tosi (1983) and Salvatori and Vidale (1997). The second cycle of excavations, that is still ongoing, began almost 18 years later with an Iranian archaeological expedition of the ICAR, directed by Sajjadi *et al*. (2003).

The site was the most ancient settlement in Iranian Sistan and excavations revealed four periods of occupations divided into eleven cultural phases (Tosi, 1973; Salvatori and Vidale, 1997). The most ancient period, period I, shows southern Turkmenian influences evidenced by clay figurines and pottery vessels similar to those of Namazga III period (Biscione, 1973; Sarianidi, 1983). The second period of occupation is dated between 2800 and 2500 BC. The first half of period III, ca. 2500-2200 BC, seems to be an continuation of the social changes of period II, but during the second part of period III signs of social/economical decline and environmental changes began to appear, leading to a great reduction of surface of the site in period IV (2200-1800 BC). By the end of period IV Shahr-i Sokhta was completely abandoned. Tosi (1973), Biscione (1974), Piperno and Tosi (1975) and Tosi (1983) The change of bed of the Hirmand River and the shifting of its inner delta, that forms the Hamun Lake, is considered one of the most important factors that played a role in the abandonment of the Burnt City.

Looking at the surface of Shahr-I Sokhta, a great amount of pottery immediately becomes visible to the eye all over the site; however, these become minimal on the surface of the graveyard where it is much less than the other areas of the sites. The pottery of Shahr-I Sokhta was made both at Shahr-i Sokhta and the

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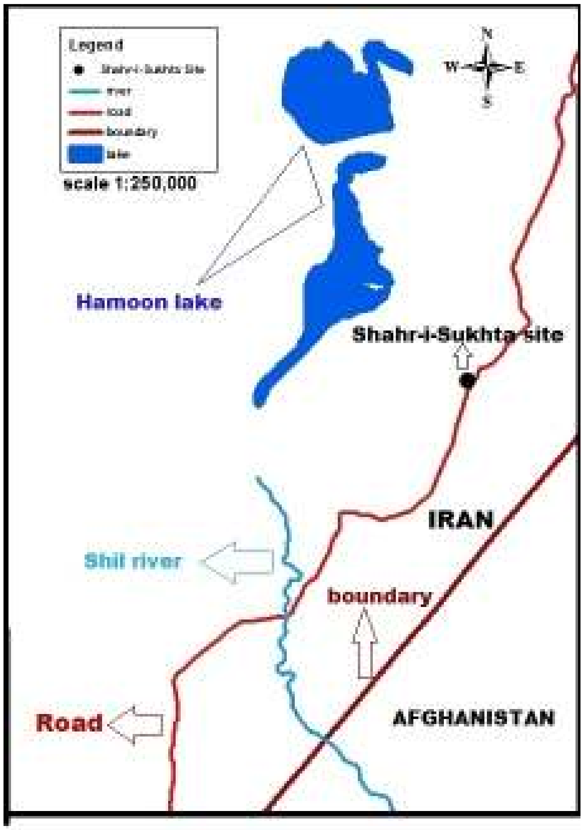

Fig. 1: Map of the Shahr-I Sukhta archaeological site (Map drawn by Maral Maleki)

artisanal areas around it, such as Tepe Dash, located 3km south of the city (Tosi, 1984) and Tepe Rudi Biyaban, 27 km south-east of Shahr-i Sokhta (Vidale and Tosi, 1996; Biscione, 1981). They are the known potters' sites in third millennium Sistan and go back to periods II and III of the sequence of Shahr-i Sokhta (Tosi, 1984). The pottery was wheel made (Vidale and Tosi, 1996) and in the majority of the cases, the color of the paste is buff. Buff ware is indeed the prevalent pottery at Shahr-I Sokhta and it ranges from an absolute buff to green. From the statistical point of view gray ware is the second in diffusion and red ware is the third (Tosi, 1983). The rich repertory of shapes of Shahr-i Sokhta's pottery can be divided into four large groups: bowls, jars, beakers and dishes. Tosi (1983) and Salvatori and Vidale (1997) estimated the presence of 58 different shapes in perid II and finally on the basis of Shepard's table he defined 186 shapes.

Many of the pottery shards found in Shahr-I Sokhta are buff in color (Fig. 2). There are other shards found which are gray and red in colour. Gray and red wares, unlike the buff wares of Shahr-I Sokhta, are prevalent in south-eastern Iran, especially in Baluchistan and in

Fig. 2: Pottery shards from Shahr-I-Soktha

the Indo-Iranian borderland, even though some of them have been found in the graves of Shahr i Sokhta. They show that the religious and formal processes of the 3rd millennium B.C. were active in the grave-goods of the graveyard of Shahr-I Sokhta and other neighboring sites. In order to determine whether the red and gray shards were locally made or imported from other sites of the region, a scientific analysis was applied to ascertain the chemical composition of the pottery shards. Compositional analysis is the best method used to determine the chemistry of the ancient artifacts such as pottery, bricks and glass beads (Bieber *et al*., 1976;

Broekmans *et al*., 2008; Marghussian *et al*., 2009; Wong *et al*., 2010; Ramli *et al*., 2011a, b, 2012; Zuliskandar *et al*., 2011). By comparing the major and trace elements of the pottery shard, we can determine whether the potteries came from the same sources or raw materials or were imported therefore the objective of this study is to determine whether the red and gray potteries are locally made or not. For archaeologists, the data of the origins of the pottery is very important for them because from the data, they can interpret the culture and trade activity of the community that they are studying.

MATERIALS AND METHODS

In total, 15 samples were gathered systematically from the surface of square XFN through archaeological excavation in the Eastern Residential Area of Shahr-i Sokhta (Fig. 1). Since the common color of the pottery at Shahr-I Sokhta is buff, therefore we collected more samples of this class to have significant results. However we also gathered two samples of gray and red pottery shards to include all classes of pottery produced at Shahr-i Sokhta. A complete description of the samples can be found in Table 1. All these fragments are dated to periods II and III, the Age of Urbanization in the Sistan basin and they are wheel-thrown (Vidale and Tosi, 1996). In these periods shapes and decorations show a very high degree of variation and many geometric, zoomorphic and floral motives appears on the pottery of Shahr-I Sokhta. Essentially the pottery shows that full-time specialists existed since the foundation of Shahr-I Sokhta. Increase of population, statehood, wheel-throwing and then the appearance of craft centre's such as Tepe Rudi Biyaban are the main reasons for mass production of pottery in the Sistan basin.

For the compositional analysis, in order to determine the chemical composition of the potteries, each samples weighing 0.4 g was refined and heated up for one hour at a temperature of 105°C and mixed until homogenous with the flux powder of a type of Spectroflux 110 (product of Johnson and Mathey). These mixtures were baked for one hour in a furnace with a temperature of 1100°C. The homogenous molten was moulded in a container and cooled gradually into pieces of fused glass with a thickness of 2 mm and a diameter of 32 mm. The samples were of 1:10 dilution. Press pallet samples were prepared by mixing 1.0 g of samples together with 6.0g of boric acid powder and then pressure of 20 psi was applied by using a hydraulic pressure equipment. The samples of fused pallets and pressed pallets were then analysed using a Philips PW1480 equipment for analysis of major and trace elements. The importance of XRD and XRF techniques has been demonstrated through its use in other fields of interest such as nano technology, environmental and earth studies and etc. (Adebiyi *et al*., 2005; Adel *et al*., 2011; Alashloo *et al*., 20011; Dhanapandian and Gnanavel, 2009; Al-Amaireh, 2006; Sedat *et al*., 2008).

Scatter plot diagrams of Al_2O_3 versus CaO, MgO versus TiO_2 and strontium versus rubidium 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 15 pottery shards samples in order to verify the presence of compositional groups of brick fragments differentiated by their probable major element sources. The

Table 1: Major elements of pottery shards excavated from Shahr-I Sokhta

Sample	Dry weight (%)									
	Si	Ti	Fe	Al	Mn	Ca	Mg	Na	K	P_2O_5	SO_3
18259-9	55.55	0.81	8.71	17.84	0.10	5.79	4.43	1.43	3.44	0.21	0.42
18260-12	50.88	0.53	5.57	12.57	0.10	12.62	6.84	3.04	1.80	0.12	0.50
18261-2	51.78	0.60	6.01	13.69	0.11	10.99	5.46	2.34	2.33	0.13	1.72
18262-6	51..27	0.44	4.71	11.13	0.09	10.40	5.87	4.73	2.65	1.39	1.05
18263-6	49.30	0.49	4.97	11.25	0.09	12.07	5.46	3.86	2.47	0.23	0.85
18264-1	49.69	0.47	4.81	10.63	0.09	12.71	7.67	2.77	2.37	0.17	2.80
18265-10	60.39	0.82	8.84	16.58	0.09	2.40	4.66	1.42	3.21	0.13	0.15
18266-13	53.14	0.73	7.22	16.60	0.08	5.00	3.74	1.82	3.42	0.15	0.34
18267-3	52.89	0.54	5.56	12.59	0.12	12.75	7.03	2.75	1.96	0.16	0.73
18268-8	52.86	0.52	5.35	12.36	0.10	11.34	5.46	2.21	2.63	0.14	2.00
18269-7	52.30	0.46	5.05	10.58	0.09	11.62	9.87	2.77	2.14	0.11	1.33
18270-11	51.34	0.58	6.10	13.29	0.11	12.36	6.00	2.25	2.74	0.30	0.73
18271-15	62.64	0.75	6.79	15.26	0.06	1.55	3.33	2.61	2.71	0.60	0.17
18272-14	47.36	0.51	4.78	10.51	0.08	12.69	5.09	3.23	3.09	0.18	2.98
18273-4	49.57	0.56	5.64	12.24	0.10	11.85	6.07	2.98	2.43	0.27	0.72

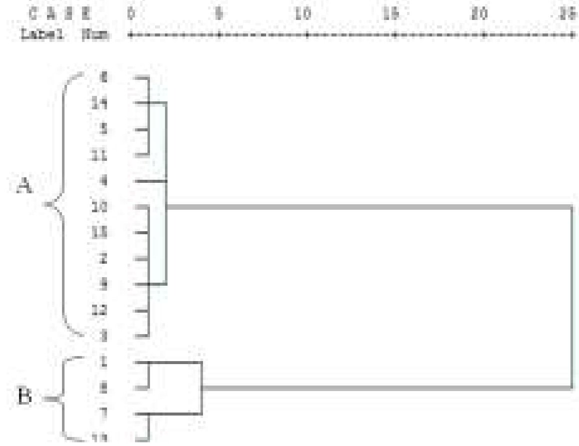

Fig. 3: Hierarchical agglomerative clustering of the Al2O3 and CaO concentration of the pottery shards from Shahr-I Sokhta

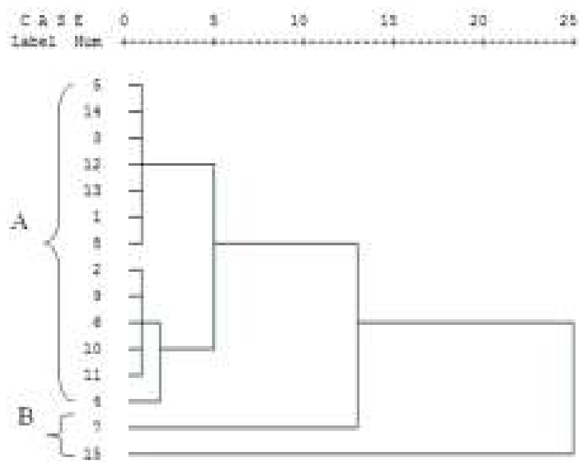

Fig. 4: Hierarchical agglomerative clustering of the rubidium and strontium concentration of the pottery shards from Shahr-I Sokhta

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 dendogram (Fig. 3 and 4) showing in the graphical form the distance between the pottery samples on the basis of their TiO_2 and MgO concentrations and strontium and rubidium concentration. The applicability of the analytical methods for the multi elemental analysis by XRF of the pottery shards is evaluated using the analysis of certified reference material, 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 CRM was also used as the quality control material of the analytical procedure.

RESULTS AND DISCUSSION

Table 1 shows the content of major elements of the pottery shards excavated from Shahr-I-Sokhta's archaeological site. The pottery samples shows quite homogeneous compositions. The range of the silica dry weight percentage is from 47.36 to 62.64%. Content of aluminum is from 10.51 to 17.84%. Content of calcium and iron are from 2.40 to 12.69 and 4.71 to 8.84%, respectively. Alkaline elements such as magnesium, sodium and potassium show content of dry weight percentage from 3.33 to 9.87, 1.42 to 4.73 and 1.80 to 3.44%, respectively. Figure 5 shows the scatter plot of Al_2O_3 and CaO and from the figure there are four samples which have different chemical composition compared to other shards, namely 18259-9, 18265-10, 18266-13 and 18271-15. These four samples shows much higher content of silica, aluminum, iron and potassium and lesser of calcium and magnesium content and therefore, we suggest that these four samples came from different areas. Hierarchical agglomerative clustering of the Al_2O_3 and CaO concentration shows that there are two component of groups which are group A that is considered as a local production of pottery shards whilst group B is considered as imported pottery shards (Fig. 3). The percentage of P_2O_5 which is average in every shards indicate that none of the shards have been used as a container for some organic materials. The high percentage of CaO in eleven of the shards shows that potter in Shahr-I-Soktha used calcareous clays as their main resources.

The content of the trace elements is shown in Table 2. The result shows that one of the pottery sample (18265-10) has a high content of lead which is of the concentration of 561 ppm. Usually lead is added as a coloring agent into the pottery and the ancient community in Indus Valley always used lead as a colorant (Caleb, 1991). However, based on the pottery shard color which is buff, we suggest that the high content of lead came from the color pigment that exists on the surface of the pottery. The sample also has a lower concentration of strontium compared to the other shards. The four samples that have been mentioned before which are 18259-9, 18265-10, 18266-13 and 18271-15, also have a higher content of vanadium compared to the other shards. The concentration of vanadium is 285, 223, 231 and 189 ppm, respectively. Figure 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 potteries. Hierarchical agglomerative clustering of strontium and rubidium concentration shows that there are also two component

Table 2: Trace element content of the pottery shards from Shahr-I Sokhta

Sample	Trace Elements (µg/g)														
	Ba	Co	Cr	Cu	Nb	U	Th	Ni	Pb	Rb	Sr	V	Y	Zr	Zn	Cl
18259-9	348	53	169	75	21	15	15	127	54	206	600	285	38	282	192	5414
18260-12	399	25	171	86	9	17	8	144	42	85	1019	131	26	241	130	10815
18261-2	438	43	155	86	18	6	18	132	79	114	677	157	28	229	131	9076
18262-6	352	29	166	42	11	6	12	93	59	113	1161	106	25	205	133	26999
18263-6	342	28	164	67	8	15	6	139	45	103	595	131	27	220	110	20208
18264-1	359	31	152	43	3	12	10	118	44	94	967	108	22	202	106	10076
18265-10	213	59	232	84	12	5	15	226	561	189	165	223	35	250	158	654
18266-13	290	47	143	96	15	8	14	90	45	198	572	231	40	247	153	2809
18267-3	355	42	146	50	9	9	17	120	100	92	1003	140	28	232	119	8641
18268-8	344	21	168	68	8	16	4	108	54	107	926	138	26	241	107	5798
18269-7	382	32	199	60	17	7	5	141	76	92	836	123	26	230	109	10976
18270-11	439	28	162	63	15	10	13	166	44	110	652	148	27	225	123	8601
18271-15	455	47	246	77	12	7	14	206	70	147	631	189	33	308	172	6352
18272-14	384	16	120	108	6	7	7	112	41	101	610	119	27	237	115	16187
18273-4	361	34	145	53	12	7	11	139	148	108	1628	154	29	215	142	13640

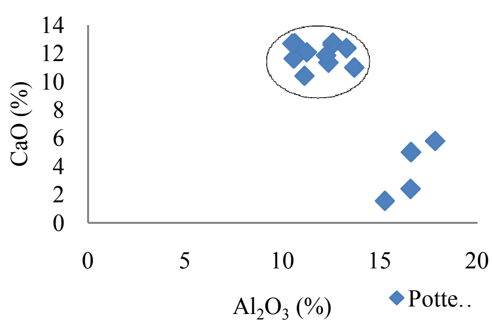

Fig. 5: The scatter plot of Al_2O_3 versus CaO

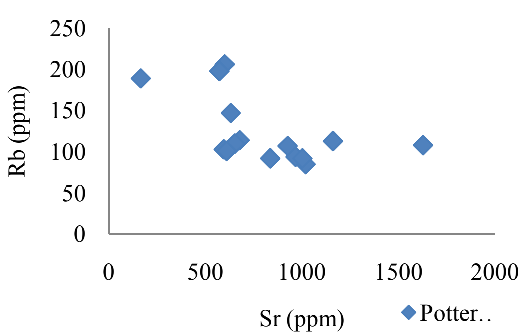

Fig. 6: The scatter plot of strontium versus rubidium

of groups which are group A and group B. Most of the samples are in group A which is consider as local production whilst group B is consider as imported pottery shards (Fig. 6). 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 18265-10 is an imported shard probably from the Indus Valley while the other three shards, namely 18259-9, 18266-13 and 18271-15 did not originated from Shahr-I-Sokhta.

CONCLUSION

The compositional analysis showed that mostly of the pottery shards taken from Shahr-I-Sokhta's archaeological site are locally made. Most of the pottery shards are made from calcareous clay as the main resources. Samples 18259-9, 18265-10, 18266-13 and 18271-15 shows that they have much higher content of silica, aluminum, iron and potassium and lesser of calcium and magnesium contents and we suggest that these four samples are not local and could be a trade items. Based on the trace element, one of the shard which is 18265-10 has a high content of lead and we suggest that this shard a probably came from Indus Valley. Based on the major and trace elements, it can be suggested that sample 18259-9, 18265-10, 18266-13, 18271-15 and 18273-4 are not locally made and the surface of the potteries are buff and red in color.

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