Analysis of Pottery Shards From New Archaeological Survey in South Region of Sistan, Iran

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ABSTRACT

The aim of this study is to determine whether pottery shards from new archaeological survey in south region of Sistan, Iran were locally made or imported from other regions. Sistan, since the Bronze Age (4000BC) until now, has had an effective and salient role in the creation of human culture and civilization in Iran. New archaeological survey in the south region of Sistan also revealed new potential archaeological sites beside the well known sites such as Burnt City, Dahaneye Ghalaman and Kuhe Khawaja. Archaeologists have divided the chronology of Sistan's history into three periods which are the prehistoric period, historical period and Islamic Period. Within these periods, many artefacts especially pottery shards have been found during the archaeological survey. These pottery shards are buff, grey, black, and red in colour which are mostly shards from broken jars, bowls, beakers and dishes. Two glaze shards from the Islamic Period decorated with floral motif have also been analyzed. In order to determine whether the glaze shards from the Islamic Period and the pottery shards from the prehistoric and historical period were locally made or otherwise,, a scientific analysis was carried out to determine the chemical composition of the shards. The technique involved the application of the X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) equipment to determine the major and trace elements and also the mineral content of the pottery shards. The results shows that most of the pottery shards taken from the archaeological survey in Sistan, Iran were locally made. Two of the samples from the Islamic Period, namely ZR332/3 and ZR369/8 show different chemical composition content compared to other shards and it can be suggested that these two samples did not originated from Sistan, Iran. A shard from the prehistoric period which is ZR028/1 also shows differences in chemical composition, suggesting that it did not originated from Sistan, Iran. The analysis of the pottery shards from Sistan shows that since the prehistoric period, there had been trade activities in Sistan and the activities continued until the Islamic Period. Results of the analysis also show that local communities in Sistan, Iran were very skilful and knowledgeable in making the pottery.

Keywords: *Sistan, X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD), pottery, Burnt City.*

INTRODUCTION

Sistan is located in the east of Iran and in the north of the vast province of Sistan and Baluchestan (see Figure 1) with an area of 8.117 square kilometres (Lashkari *et al*. 2012). Sistan with its rich culture, has many unspoken words at the bottom of its fluid geomancy and heavy alluviums. Continuous attempts by archaeologists and comprehensive studies by researchers have shown a new face of the history of this region, which today is only a desert. Sistan since the Bronze

Age until now has had an effective and salient role in the creation of human culture and civilization in Iran (Sarhaddi Dadian et al. 2012: 312). Burnt City (Sajjadi, 2008: 307; Tosi, 1983a: 73-125), Dahaneye Ghulaman (Slaves Throat), (Scerrato, 1977: 709-735; Latere and Genito, 2010: 77), and Kuhe Khawaja (Khawaja Mountain), (Bater, 2010; Ghanimati, 2000: 137-150), etc. are not counted as the only historical places of Sistan that have been identified. There are several cities and oasis, which have hidden many secrets within. The first human settlement in this area was dated to the late fourth millennium BC, the period, which is called as Bronze Age (Sajjadi and Casanova, 2006: 347-357).

It coincides with the beginning of urbanization in the Middle East (Alden, et al. 1982: 613-640). This period lasted until the early second millennium BC, in which many sites have been identified in southern Sistan and the Share Sokhta is one of the hundreds sites from this period. (Vidale & Tosi 1996: 251-269; Biscione 1987: 394). Each of the sites is abundant in pottery shards, which are different from those of other periods in terms of type, shape, decoration, and technical characteristics. The main features of the potteries consist of geometrical, plant, and animal pattern decorations in the inner and outer parts of the containers, which decorated in black or ochre colours on the buff or light grey slips (Tosi 1983: 136-139, Salvatori & Vidale 1997). From the Bronze Age until the Achaemenian Empire (550 BC), there was no evidences of earthenware, and other cultural materials in Sistan. Therefore, we have a big gap from 1800 BC to 550 BC in the Sistan Region.

The second period of the potteries in Sistan belonged to the Iranian historical periods (550 BC-550 AD) during which the dynasties of Achaemenid, Parthian, and Sassanid had the large parts of the Middle East under their control (Chavalas, 1999: 88).

One of the important features of the potteries is that they were without any decoration on their internal and external surface. The decoration of the potteries were simple such as the excised decoration on the outer part. Additionally, others major characteristics are such as the dense, smooth and burnished slip, and the dough's colours was red (Mehrafarin & Musavi, 2011: 240-58).

From the late Sassanid period (sixth century AD) to 13th century AD, earthenware was not found in Sistan. After this period many new sites were detected in Sistan, which have many potshards. The potteries of this period are different from the previous two periods in terms of the shape and decoration, which coincided with the Islamic middle period in Sistan. The Islamic potteries were decorated in various colours. The most important glaze colours included green, bluish gray, milky and black and the potteries were decorated with specific decorations such as the excised motifs under the glaze or glazed in black colour (black pen), and also geometric and plants decorations under light glaze. The dominating form is the open mouth bowl with a flat base. The dough's colour in the Islamic Period included light buff (Mousavi & Atai, 2010).

Four parts were selected for field work in the southern Sistan Basin that included the Shileh River, Gerdi Castle, South of Rostam Castle, and south of Hamoon Lake zones. They were surveyed systematically. The areas for those parts totalled 2223 square kilometres. During the survey 95 sites were detected including 20 sites from the Shileh River, 3 sites from the South of Hamoon Lake, 47 sites from the Gerdi Castle district, and 25 sites from south of Rostam Castle. About 626 pottery shards were selected from the surface of the sites.

Most of the pottery shards found from the survey in several sites from Sistan belonged to the historical period. Three of the samples belonged to the prehistory period and two of the samples belonged to the Islamic period. Pottery shards from the prehistoric and historical periods were buff, grey, red and black in colour. Previous study showed that grey and red wares, unlike the buff wares of Shahr-I Sokhta, are prevalent in south-eastern Iran, especially in Baluchistan and in the Indo-Iranian borderland, even though some of them have been found in the graves of Shahr- I - Sokhta (Hossein et al. 2013:). Scientific analysis on the pottery from Shahr-I-Sokhta showed that some of the buff and red shards were imported item and the high content of lead indicated that the shards are originated from the Indus Valley (Hossein et al. 2013:). Two of the Islamic potteries were decorated by flora motif and the surface was covered by glaze. Sample ZR332/1 was decorated with flora motif which in blue colour while sample ZR369/8 was decorated with flora motifs in brown, blue and red colours. The origin of these two shards is unknown and the possibility that these two shards are not of local origin is high, in addition the shards are dated to the Safavid period (Lane, 1947; Lane, 1948, Pl. 32A).

Compositional analysis is the best method that can be used to determine the chemical of the ancient artefacts 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, 2011b, 2012; Zuliskandar et al. 2011a, 2011b, 2013a, 2013b). By comparing the major and trace elements of the pottery shards, we can determine whether the potteries came from the same sources or whether the raw materials were local or were imported. Chemical composition of artefacts also being compared with chemical composition of clay or raw materials located near the location of the artefacts (Zuliskandar et al. 2014a, 2014b, 2014c). Therefore the objective of this study is to determine whether all the pottery shards collected in the different sites of Sistan were locally made or otherwise. For archaeologists, the data of the origins of the pottery are crucial because the archaeologists can, based on the data, interpret the culture and trade activity of the community that they are studying.

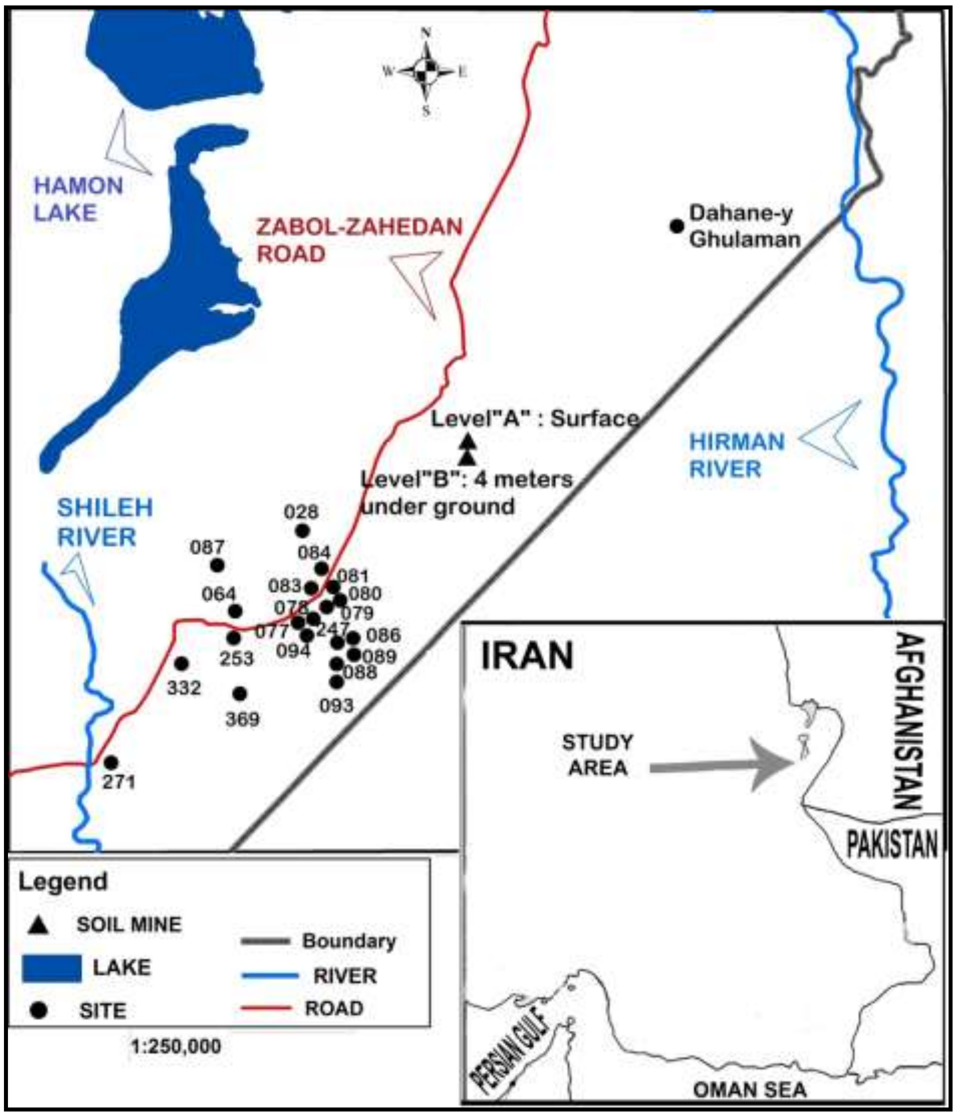

Figure 1. Location of the sites where pottery shards have been taken
(Map drawn by Maral Maleki)

MATERIALS AND METHOD

In total, 22 pottery shards of different periods were chosen from the Sistan region for chemical analysis for chemical analysis and soil samples from one of the mines in Sistan were collected for raw material sample using laboratory methods where soil was collected from two levels, namely the surface level and 4 metres underground to compare them with the ancient potsherds of Sistan. This is in order to find out if these potsherds were made using the soil from Sistan or if the soil used was transported from other places. Additionally, the survey also sought to find out the differences among the potsherds of Sistan that belonged to different periods, namely the prehistoric, historical and Islamic periods. The mine from which the 30g of soil was collected is located 3 kilometres south of the Share Sokhta site from which the Sistanian people at the present day also collects the same soil to make pottery and bricks. The Shahre Sokhta site is also situated 56 kilometres south of the modern city of Zabol.

As mentioned earlier, the potshards are divided into three categories, namely the prehistoric period, historical period and Islamic period. Three prehistoric pottery shards were selected, which were 028/1, 087/6, and 253/1. The pottery was wheel made and in the majority of the cases, the colour of the paste is buff. Buff ware is indeed the prevalent pottery in the Sistan Region and it ranges from an absolute buff to green. From the statistical point of view gray ware is the second in diffusion while red ware is the third. We also gathered two samples of gray, one red and one buff pottery shards to include all classes of pottery produced during the prehistoric period, which are comparable to the Shahre Sokhta site, in term of their fo shape, colour and the motifs and dated to the third millennium BC in Sistan region (Tosi 1983b: 132).

There is a cultural gap after the prehistoric period in the Sistan Region. The historical period started from the Dhane Ghulaman site. Unfortunately, there were no evidences of Iron Age in the Sistan Region after the archaeological survey in the whole plain of Sistan. Still the Iron Age is unknown in this region to us; probably the evidence of this period has been covered by the flood sediments during the thousand years and has been carried out by the Hrimand River into the Sistan region. The variety of potteries shows that they have been an important and useful products during the history of Sistan.

17 pottery shards were selected from the historical sites for the chemical studies, because most of the historical sites, which have been discovered in this research belonged to the historical periods. The potshards include 061/4, 077/2, 078/8, 079/5, 080/4, 081/2, 083/4, 084/3, 086/3, 247/4, 088/3, 089/2, 093/2, 094/1, 253/4, 271/5 and Dahane-y Gulaman 2001/26/2. A large group of potteries, which have been detected from the districts of Shileh River, Rostam Castle, South of Hamoon Lake, and Gerdi were simple and they belonged to the historical periods, especially, the Achaemenian Empire (Sarhaddi Dadian, 2013). In total we were able to figure out the settlements of the Achaemenid period in the Sistan Region, thus the potteries do not have any decorative motifs. The colours of the pottery shards are buff, light red (brick colour), and red. The temper consisted of minerals and a little vegetation. It is very hard to figure out the forms of those potteries from the potshards. We can mention several shapes such as bowls and vases with open mouth, flat rims, and bowl with inverted and averted rims. We can also mention cups with smooth edge and flat body. In total, the decorative motifs of those potteries include excised decoration, and added motifs, and from the excised decoration, we can point out the grooved designs. It seems that the creation of grooves of horizontal lines started from the Achaemenian Period and developed in the later period. The human stylized motif is the design that has been found on the potteries of the Dahaney Ghulaman site, and usually these motifs are decorated on the outer surface of the cups, which are of the same size on their mouth and body (Genito, 1990: 588-601).

The pottery of the Parthian Period is considerable different from the ones of the Achaemenian Period in terms of form and style. Most of potteries are simple, and they are usually covered in different slips such as buff, light and dark red. Pottery with excised decoration is still one of the common motifs in the Parthian Period in the Sistan Region (Haerinck, 1980: 43-54; Mehrafarin & Musavi, 2011: 240-258)

According to the archaeological survey, there were not many settlements of the Sassanid in the south of Sistan, and there are little evidences about this period in those parts of Sistan unlike the other parts. The features of the pottery of the Sassanid Period continue from the Parthian Period. In this period, the ceramics are without glaze, and the dominant colour is red as in the previous stage. Most of the potteries are quite simple and are covered with thick layer and in some cases their surfaces are covered with thick mud slurry. The dominant colour of the pottery are the Sistani grooved pottery style and very common in this period. The new sample of the pottery that we can mention is the mould motifs (stamp). The decorative motifs are often geometric and have plants designs. (Mehrafarin and musavi, 2010: 256-272)

The evidences of the Islamic Period have been detected in the sites No. 332, sample No. 3; and site No. 369, sample No. 8. The potteries of this period are very different from the other periods in Sistan Region. Those potteries, similar to most are as most other parts of Iran are glaze; in addition, they are divided into painted pottery with glaze and non-glaze, simple pottery without slip and simple pottery with excised decoration. (Mousavi & Ataie, 2010: 302-321). The tempers of the potteries are mineral. Their designs includes zigzag lines and small circles. The painted pottery with glaze is a type of potshards that have been found in the sites of 332/3 and 369/8. The plant motifs are in red, brown and blue on milky background under clear glaze, which are dated to the Safavid period (Lane, 1947; Lane, 1948, Pl. 32A). We can mention special types of pottery such as those with painting under the blue glaze, which include geometric and plants motifs. They are comparable to the potteries of 6-13 A.D in the south of Sistan. (Golombek, 2003: 253-270; Scanlon, 1984)

For the analysis, in order to determine the chemical composition of the potteries, each sample weighing 0.4g 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 & 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 2mm and a diameter of 32mm. The samples were of 1:10 dilution. Press pallet samples were prepared by mixing 1.0g of samples together with 6.0g of boric acid powder and then pressure of 20 psi was applied by using hydraulic pressure equipment. The samples of fused pallets and pressed pallets were then analysed using a Philips PW 1480 equipment for analysis of major and trace elements.

Scatter plot diagrams of SiO_2 versus CaO, 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 silica (SiO_2) and calcium (CaO), strontium and rubidium, of all 22 pottery shards samples in order to verify the presence of compositional groups of brick fragments differentiated by their probable major element sources. The 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. 4 & 6) showing in the graphical form the distance between the pottery samples on the basis of their SiO_2 and CaO percentage 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.

Figure 1. Pottery shards from several archaeological sites in Sistan, Iran

Figure 2. Pottery shards from several archaeological sites in Sistan, Iran

RESULT AND DISCUSSION

X-Ray Diffraction analysis (XRD) on 22 pottery shards and two clay samples was conducted to determine the mineral content in the shards and also clay samples (see Table 1). Analysis on shards from the Prehistoric period (ZR028/1, ZR087/6, ZR253/1) shows that the shards contain mineral such as quartz, albite, dickite, haematite, anorthite and diopside. Two shards (ZR332/3, ZR369/8) which are from the Islamic Period with motif and colour glaze on the surface contained minerals such as quartz, gypsum and calcium sodium aluminium silicate. Sample ZR332/3 only has quartz as the remaining mineral and this shows that the sample was fired at very high temperature exceeding 1000˚C. The rest of the pottery shards are from the Historical period and contained mineral such as quartz, diopside, anorthite, albite, andesine, labradorite and minor mineral such as palladium, cuprite, giniite and gypsum. Quartz, calcite, clinochlore, muscovite, dolomite, chamosite and albite are the minerals present in the clay samples taken from the ancient oasis in Sistan. Diopside mineral was only present in the pottery shards but not present in the clay samples. Two of the shards (ZR087/1, ZR253/1) from the prehistoric period had diopside while most of the shards from the historic period contained diopside mineral. Diopside is found in ultramafic (kimberlite and peridotite) igneous rocks, and diopside-rich augite is common in mafic rocks, such as olivine basalt and andesite. Diopside is also found in a variety of metamorphic rocks, such as in contact metamorphosed skarns developed from high silica dolomites. We suggest that diopside mineral in the shards probably came from dolomite present in the clay samples.

Table 2 shows the content of the major element of the pottery shards taken from several potential archaeological sites in Sistan. The pottery samples show quite homogeneous composition except for two samples from the Islamic Period. The range of the silica dry weight percentage for the shard categories of the prehistoric and historical period is from 43.36 to 56.32%. Content of aluminium is from 11.66 to 16.75%. Content of calcium and iron are from 4.11 to 13.80% and 5.06 to 7.64%, respectively. Alkaline element such as magnesium, sodium and potassium shows content of dry weight percentage from 4.29 to 7.04, 1.32 to 3.12 and 1.20 to 3.25%, respectively. Two samples from the Islamic Period shows different data in which the range of silica dry weight percentage is much higher (77.56-78.98%), with very low calcium (2.23-2.48%), a lower content of magnesium (0.03-1.185) and potassium (1.32-1.46) and much higher sodium (4.85-5.47%) compared to other shards from the Prehistoric and Historical period. Sample ZR369/8 also has a very low content of iron (0.79%) compared to other samples. Figure 1 shows a scatter plot of SiO_2 and CaO and from the figure it clearly shows that two shards from the Islamic Period, namely ZR332/3 and ZR369/8 have different chemical composition compared to other shards. These two samples show much higher content of silica and sodium and lesser of aluminium, calcium, iron, and potassium content and therefore, we suggest that these two samples came from other regions, probably from outside of Iran. Hierarchical agglomerative clustering of SiO_2 and CaO percentage shows that there are three components of groups; these are group A that is considered as local production of pottery shards and has significant value below 5; group B which is also considered as a locally produced pottery shards which has significant value below 10 and finally, group C which is considered as imported pottery shards (see Figure 3). The percentage of P_2O_5 which is average in every shards indicate that none of the shards have been used as container for some organic materials. The high percentage of CaO in the shards shows that potters in Sistan used calcareous clays as their main resources.

The content of trace elements is shown in Table 3. The result clearly shows that two shards from the Islamic period have very different chemical content. The shards have very high content of lead (1500ppm, 3700ppm), cobalt (100ppm, 300ppm) and barium (3000ppm, 4500ppm) but lower in rubidium (15ppm, 24ppm). Analysis on Shahr-I-Sokhta pottery shards also showed that one of the pottery shards has a high content of lead (Hossein et al. 2013). Lead is usually added as a colouring agent into the pottery by ancient potters and archaeological research confirms that the ancient community in the Indus Valley had always used lead as a colorant (Caleb 1991). No lead was detected in the prehistoric and historical period shards and therefore our suggestion that both shards from the Islamic Period are not originate from this region is strongly supported. Figure 4 shows the scatter plot of strontium versus rubidium; it shows that most of the prehistoric and historical pottery shards and also the clay samples are in one group. The Islamic Period shards however, belonged to another group which is non local pottery product. Some of the shards (ZR078/8, 081/2,/061/4) contained much higher strontium compared to the other shards. Hierarchical agglomerative clustering of strontium and rubidium percentage shows that there are three components of groups which are group A that is considered as local production of pottery shards and has significant value below 5; group B which is also considered as a mixture of local production and imported pottery shards that has significant value below 10 and group C that is considered as pottery shards which have a much higher content of strontium (see Figure 4).

CONCLUSION

The compositional analysis showed that most of the pottery shards taken from the archaeological survey in Sistan, Iran were locally made. Two of the samples from the Islamic Period which are ZR332/3 and ZR369/8 showed different chemical composition compared to the other shards. These two shards have a much higher content of silica, very low calcium, magnesium and potassium and much higher sodium compared to the other shards from the prehistoric and historical period. The shards also have a much higher concentration of lead, cooper (ZR332/3) and cobalt. We strongly suggest that these two samples did not originate from Sistan, Iran. A shard from the prehistoric period which is ZR028/1 also showed a difference in its chemical composition. Sample ZR028/1 has a lower content of calcium and a higher content of potassium compare to the other shards from the prehistoric and historical period. The mineral content also differ from other shards. We suggest that sample ZR028/1 did not originated from Sistan, Iran. The analysis of the pottery shards from Sistan showed that since the prehistoric period, there had been trade activity in Sistan and the activity continued until the Islamic Period. The result of the analysis also showed that the local community in Sistan, Iran were very skilful and knowledgeable in making the pottery.

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Table 1. Content of mineral in the pottery shards and clay samples

Sample	Mineral Content
ZR332/3	Quartz, syn SiO_2
	Calsium Sodium Aluminum Silicate $Ca_{0.8}Na_{0.2}Al_{1.8}Si_{2.2}O_8$
	Gypsum $CaSO_4.2H_2O$
ZR028/1	Quartz, syn SiO_2
	Albite, calcian, ordered $(Na,Ca)Al(Si,Al)_3O_8$
	Dickite $Al_2Si_2O_5(OH)_4(HCONH_2)$
	Haematite Fe_2O_3
ZR087/6	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Anorthite, sodian, ordered $(Ca,Na)(AlSi)_2Si_2O_8$
	Albite, disordered $Na(Si_3Al)O_8$
ZR077/2	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Anorthite, sodian, ordered $(Ca,Na)(AlSi)_2Si_2O_8$
	Albite, disordered $Na(Si_3Al)O_8$
ZR078/8	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
ZR079/5	Anorthite $CaAl_2Si_2O_8$
	Andesine $Na_{0.622}Ca_{0.368}Al_{1.29}Si_{2.71}O_8$
	Quartz, syn SiO_2
ZR080/4	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
ZR081/2	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Albite, calcian, ordered $(Na,Ca)Al(Si,Al)_3O_8$
ZR083/4	Quartz, syn SiO_2
	Anorthite, ordered $CaAl_2Si_2O_8$
	Labradorite $Ca_{0.65}Na_{0.35}(Al_{1.65}Si_{2.35}O_8)$
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
ZR084/3	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
ZR086/3	Quartz, syn SiO_2
	Albite, calcian, ordered $(Na,Ca)Al(Si,Al)_3O_8$
	Anorthite $CaAl_2Si_2O_8$
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
ZR247/4	Quartz, syn SiO_2
	Albite, calcian, ordered $(Na,Ca)Al(Si,Al)_3O_8$
	Anorthite $CaAl_2Si_2O_8$

	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Andesine $Na_{0.622}Ca_{0.368}Al_{1.29}Si_{2.71}O_8$
ZR088/3	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Tephrite $(Mg, Fe,Al, Ti)(Ca, Fe, Na, Mg)(Si,Al)_2O_6$
	Albite calcian low $(Na_{0.75}Ca_{0.25})(Al_{1.26}Si_{2.74}O_8)$
ZR089/2	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Anorthite, ordered $CaAl_2Si_2O_8$
ZR253/4	Quartz, syn SiO_2
	Albite, calcian, ordered $(Na,Ca)Al(Si,Al)_3O_8$
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Pyrocene (Mg0.998Fe0.002)(Ca0.999Fe0.028)(Si2O6)
	Andesine $Na_{0.622}Ca_{0.368}Al_{1.29}Si_{2.71}O_8$
ZR253/2	Quartz, syn SiO_2
	Palladium (H-Loaded), syn Pd
	Cuprite Cu_2O
	Giniite, ferric, syn Fe5(PO4)4(OH)3.2H2O
	Gypsum $CaSO_4.2H_2O$
ZR093/2	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Anorthite, ordered $CaAl_2Si_2O_8$
ZR094/1	Quartz, syn SiO_2
	Calcite $CaCO_3$
	Albite high (K0.02,Na0.78)($AlSi_3O_8$)
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
ZR271/5	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Anorthite, sodian, ordered $(Ca,Na)(AlSi)_2Si_2O_8$
	Albite, disordered $Na(Si_3Al)O_8$
ZR369/8	Quartz, syn SiO_2
	Calsium Sodium Aluminum Silicate $Ca_{0.8}Na_{0.2}Al_{1.8}Si_{2.2}O_8$
	Gypsum $CaSO_4.2H_2O$
ZR061/4	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
Ghulaman	Quartz, syn SiO_2
	Diopside $Ca(Mg, Al)(Si, Al)_2O_6$
	Albite, calcian, ordered $(Na,Ca)Al(Si,Al)_3O_8$
Clay A	Quartz, syn SiO_2
	Calcite, $CaCO_3$
	Clinochlore-1MIIb, ferroan, $(Mg,Fe)6(Si,Al)_4O_{10}(OH)_8$
	Muscovite, $KAl_2Si_3AlO_{10}$
	Dolomite $CaMg(CO_3)_2$
	Chamosite $(Mg_{5.036}Fe_{4.964})Al_{2.724}(Si_{5.70}Al_{2.30}O_{20})(OH)_{16}$
	Albite, calcian, ordered, $(Na, Ca)Al(Si,Al)_3O_8$
Clay B	Quartz, syn SiO_2
	Calcite, $CaCO_3$
	Clinochlore-1MIIb, ferroan, $(Mg,Fe)6(Si,Al)_4O_{10}(OH)_8$

Muscovite, $KAl_2Si_3AlO_{10}$
Dolomite $CaMg(CO_3)_2$
Chamosite $(Mg_{5.036}Fe_{4.964})Al_{2.724}(Si_{5.70}Al_{2.30}O_{20})(OH)_{16}$
Albite, calcian, ordered, $(Na, Ca)Al(Si,Al)_3O_8$

Table 2. Content of major elements in the pottery shards and clay samples

Sample	Dry Weight (%)									
	Si	Al	Ca	Fe	Mg	Mn	Na	K	Ti	P_2O_5
ZR332/3	77.56	3.13	1.52	0.48	0.93	0.02	4.85	1.32	0.11	0.09
ZR028/1	56.32	16.73	4.10	7.64	4.84	0.09	1.34	3.02	0.77	0.14
ZR087/6	52.04	15.08	9.78	6.52	5.07	0.12	2.19	2.55	0.67	0.20
ZR077/2	52.37	15.43	9.07	6.31	6.10	0.10	2.01	2.58	0.64	0.12
ZR078/8	43.98	13.16	13.64	6.04	5.02	0.14	2.16	2.27	0.58	0.41
ZR079/5	48.75	14.59	12.28	6.00	7.04	0.11	3.12	1.20	0.63	0.23
ZR080/4	54.76	12.55	10.21	5.12	6.68	0.10	2.56	2.09	0.52	0.31
ZR081/2	50.45	14.76	7.90	6.60	4.99	0.10	2.28	2.62	0.64	0.91
ZR083/4	50.59	15.34	8.77	7.38	4.29	0.11	1.41	3.20	0.69	0.31
ZR084/3	48.83	14.57	12.81	6.42	5.49	0.13	1.82	2.39	0.71	0.31
ZR086/3	55.18	15.22	6.68	6.10	4.93	0.11	2.43	3.19	0.62	0.26
ZR247/4	54.68	15.95	8.71	6.35	5.34	0.10	2.32	2.47	0.61	0.25
ZR088/3	53.98	12.79	11.78	5.16	5.48	0.09	2.53	1.90	0.58	0.16
ZR089/2	47.93	14.33	11.57	6.32	5.27	0.11	2.86	1.81	0.66	0.18
ZR253/1	53.15	16.75	8.53	6.87	5.79	0.12	2.02	2.74	0.66	0.13
ZR253/4	49.67	14.96	11.22	6.76	4.67	0.13	1.32	2.93	0.72	0.18
ZR093/2	53.59	15.79	9.18	6.28	5.02	0.11	1.98	2.81	0.61	0.42
ZR094/1	43.36	13.46	11.20	5.20	6.92	0.10	2.01	2.13	0.50	0.18
ZR271/5	53.51	14.60	9.43	6.21	4.73	0.13	2.26	2.31	0.67	0.15
ZR369/8	78.98	3.88	2.23	0.79	1.18	0.02	5.47	1.46	0.12	0.09
ZR061/4	45.49	11.66	12.92	5.06	7.17	0.09	2.52	1.56	0.53	0.33
Ghulaman	50.51	16.67	6.11	7.82	4.90	0.12	2.10	3.25	0.75	0.38
Clay A	45.56	13.14	12.94	6.95	4.57	0.13	0.87	2.60	0.78	0.15
Clay B	45.47	13.03	13.80	6.45	4.74	0.13	0.88	2.57	0.72	0.14

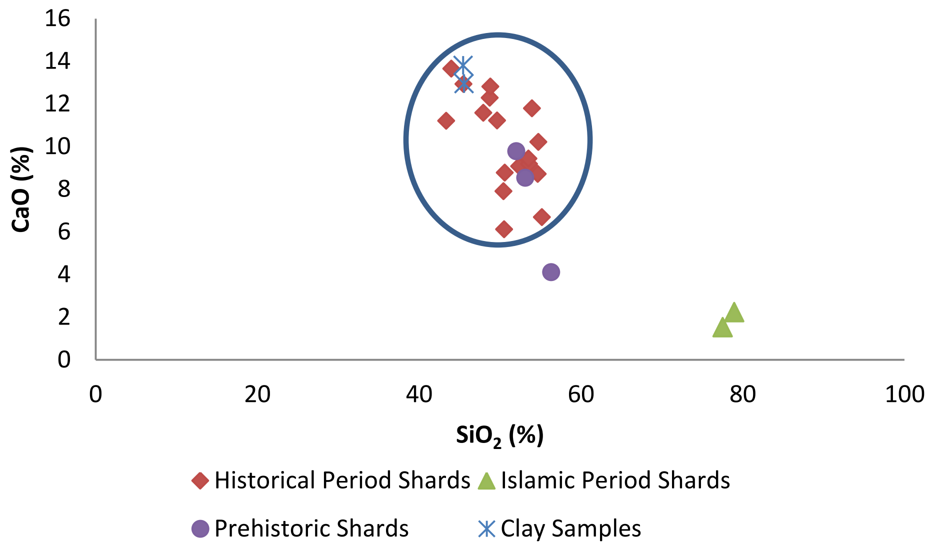

Figure 1. Scatter plot of the SiO_2 and CaO percentage of the pottery shards from several sites at Sistan, Iran

Table 3. Content of trace elements in the pottery shards and clay samples

Sample	ppm (µg/g)									
	Pb	Cu	Ba	Sr	Zr	Rb	Zn	SO_3	Cl	Co
ZR332/3	1500	200	3000	216	100	15	58	2400	2300	100
ZR028/1	nd	89	400	306	200	104	200	1100	400	nd
ZR087/6	nd	68	400	415	100	90	100	1300	600	nd
ZR077/2	nd	88	500	425	100	108	100	2700	800	14
ZR078/8	nd	61	600	900	400	118	nd	22700	1200	nd
ZR079/5	nd	66	nd	406	200	38	100	900	800	24
ZR080/4	nd	56	nd	510	100	66	200	2200	800	28
ZR081/2	nd	79	500	1000	400	123	100	7000	2500	34
ZR083/4	nd	70	500	305	100	125	300	500	200	nd
ZR084/3	nd	81	500	424	200	105	100	1600	400	nd
ZR086/3	nd	62	500	432	100	107	100	3100	4000	29
ZR247/4	nd	46	600	514	100	104	100	1000	500	nd
ZR088/3	nd	51	600	519	200	69	100	700	500	nd
ZR089/2	nd	63	nd	411	100	87	100	2300	1600	nd
ZR253/1	nd	72	600	419	100	113	200	700	400	nd
ZR253/4	nd	84	500	526	200	115	100	1400	600	nd
ZR093/2	nd	68	600	529	100	118	100	1500	900	nd
ZR094/1	nd	70	800	700	500	63	200	8000	1300	21
ZR271/5	nd	67	400	312	100	104	100	600	800	32
ZR369/8	3700	57	4500	323	200	24	nd	3200	4100	300
ZR061/4	nd	94	400	1100	400	52	nd	16000	2200	nd
Ghulaman	nd	90	600	320	100	107	nd	1800	2000	40
Clay A	nd	83	nd	325	96	98	110	2000	100	4
Clay B	nd	80	nd	330	100	109	100	500	nd	nd

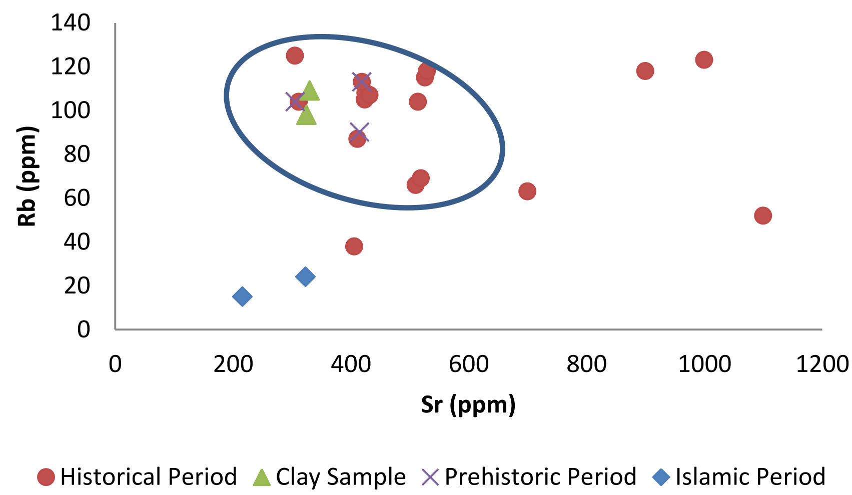

Figure 2. Scatter plot of the strontium and rubidium concentration of the pottery shards from several sites at Sistan, Iran

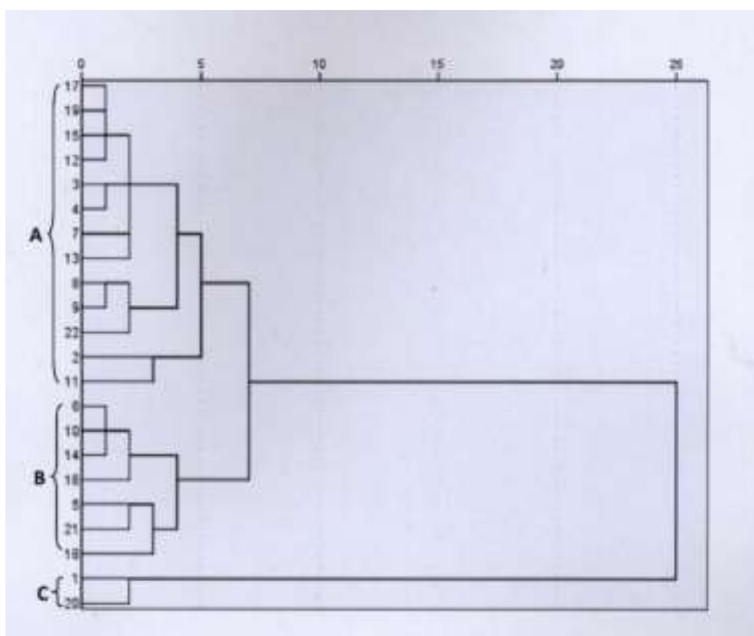

Figure 3. Hierarchical agglomerative clustering of the SiO_2 and CaO percentage of the pottery shards from several sites at Sistan, Iran

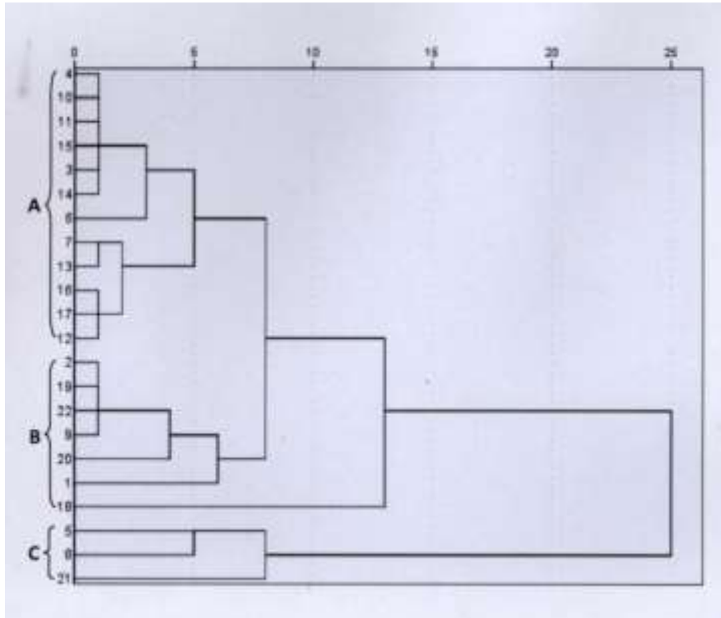

Figure 4. Hierarchical agglomerative clustering of the Strontium and Rubidium concentration of the pottery shards from several sites at Sistan, Iran