Correlation Between Grain Size Distribution and Silicon and Oxygen Contents at Wadi Arar Sediments, Kingdom of Saudi Arabia

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Abstract—**Quartz is the major mineral of Wadi Arar sediments. The top two elements contents are oxygen with 63.96 wt%, followed by silicon with 16.35 wt%. There is a positive, weak to medium correlation between grain size and silicon and oxygen contents. The correlation between oxygen and grain size is four times higher than that of silicon. At grain size ranges between 0.8 and 1.0 mm, both oxygen and silicon show the maximum correlation, which decrease gradually with finer and coarser grain sizes. For each element, the correlation between the element content and grain size is a fourth degree polynomial in the grain size. Theoretically, the best two math models that represent the relation between the grain size distribution and each of individual oxygen and silicon content are $y=8.84 \cdot \ln(x)+39.5$ and $y=2.26 \cdot \ln(x)+10.1$ respectively, where y represents the element content percentage and x represents the corresponding grain size in mm.**

Keywords- quartz; silicon; oxygen; grain size

I. INTRODUCTION

Wadi Arar is located in the central part of the Northern Border Region of the Kingdom of Saudi Arabia (KSA). It penetrates Arar City from the south west to the north east and divides Arar city into two regions (Figure 1). These regions and areas are characterized by a rocky layer of limestone and sandstone with a few of dolomite and silt. A few studies and boring reports about soil properties of Wadi Arar for foundations and projects construction were done [1]. Analysis of grain size distribution has been widely used by engineering geologist and sedimentologists to classify sedimentary environments and investigate transport dynamics. Grain size is also an important biotic component of the dune ecosystem. The grain size of sediments provides an indication of the shear stress that must be applied by the medium to initiate and sustain particle movement. Grain size distribution is affected by other factors such as distance from the shoreline, distance from the recharge source area, source material, topography and transport mechanisms. The essential factors influencing the heavy metal contents in sediments include the physical and chemical properties (grain size, surface to volume ratio, heavy metal contents of the main geochemistry phase), in which grain size is a main control parameter. There is an indication that finer sediments contain more heavy metals than coarser ones. The main reason is that smaller grain size particles have a larger surface-to-volume ratio [2, 3]. However, some studies have indicated that coarser particles show a similar or even higher heavy metal concentration than finer ones and the presence of coarser particles are possibly responsible for higher metal content in the coarser size fractions [4, 5].

In [6], authors observed that the radon exhalation rate increases with an increase in grain size. In [7], authors found that the maximum concentrations of the platinum group and rare earth elements were observed at d50=1-2 and 1-4 μm respectively. In [8], the grain size distribution and heavy minerals at Malindi Bay coast, Kenya were investigated. In [9], authors showed that the heavy metals concentrations increased with the decrease in particle size. In [10], it was found that most of elements have their highest concentrations in fine grain mud samples when compared with silt and silt-mud samples, with clay minerals possibly playing an important role. In [11], authors quantified mineral grain size distributions for process modelling using X-ray micro-tomography. In [1], it was found that deposits of Wadi Arar were silty sand (SM) according to unified soil classification system. In [12], authors concluded that if the grain size decreases, heavy metal content increases. In [13], authors showed the strong influence of grain size on sediment composition that is largely reflecting the greater grain size effect on mineralogy. In [14], authors found a distinct heterogeneity in particle size distribution and mineralogy throughout the Boulder Creek Watershed in Colorado, USA.

There are not enough studies available to correlate grain size distribution with each of the two elements (silicon and oxygen) composing of Quartz at Wadi Arar, Kingdom of Saudi Arabia. Accordingly, the present work is mainly focused on the Quartz mineral. It is attempting to portray the grain size distribution of quartz mineral content on silicon and oxygen percentages at Wadi Arar. Therefore, the study area is carefully chosen to represent a key sector of Quartz mineral content due to urban expansion in Arar city. Also, the present study is focuses on the part of Wadi Arar which will probably be developed for real estate (Figure 1). Figure 2 shows an explanation diagram of the scope and purpose of the present work.

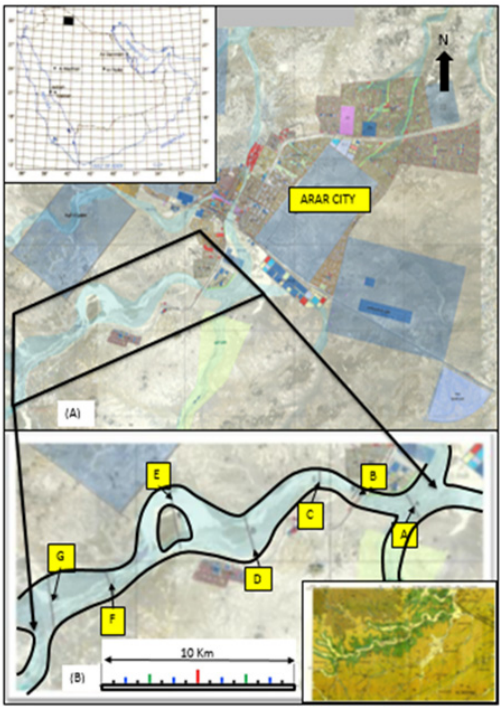

Fig. 1. Topographical Plan of Arar City and Wadi Arar (after Alghamdi and Hejazy, 2013)

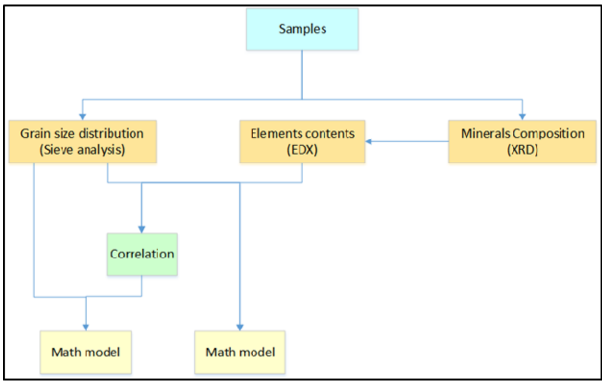

Fig. 2. Illustration diagram of the scope and purpose of the work.

II. GEOLOGICAL SETTING

The study area which located in the northwestern part of Saudi Arabia is underlain by Late Cretaceous sedimentary rocks of the Aruma Group and by Paleogene and Neogene sedimentary rocks, Devonian, Silurian, Ordovician, and possible Cambrian sedimentary units occurring in the subsurface. Nonconsolidated gravel, sand and silt occupy most wadis and dissolution-subsidence depressions [15].

III. METHODOLOGY

A. Sampling

For the purpose of measuring grain size distribution, thirty five disturbed samples were collected from seven locations in Wadi Arar, five from each location. The profiles of the locations were denoted by A, B, C, D, E, F and G profiles. Profile A is located at the northeast point of the Wadi facing Arar city while profile G is located at the southeast point facing Aljouf city. For the purpose of mineral and element analysis, three disturbed samples are taken from each location of each profile (Figure 1).

B. Sieve analysis

Grain size distribution data are obtained using the sieve analysis test [1]. Geometric means of percentages were calculated rather than arithmetic means because the geometric mean is more suitable when percentages are used.

C. X-ray diffraction (XRD)

The X-ray diffraction patterns of the selected soil samples under study were carried out using a Phillips X, PANalytical x-ray diffractometer at 40 kV and 40 mA with Ni Filter and Cu Kὰ radiation. The XRD runs were carried out up to 2θ 0f 69^o. The traditional XRD patterns obtained from the current samples show more or less similar 2θ of the diffraction peaks.

D. Heavy liquid separation technique

Each of the investigated samples was subjected to heavy liquid separation technique using bromoform (sp. gr.=2.8) where most of quartz mineral is obtained in the light fraction while all of remaining mineral varieties were obtained in the heavy fraction. Each of the individual light fraction was detected using scanning electron microscope.

E. EDX

Energy-dispersive X-ray spectroscopy (EDX) analysis technique was used for the elemental analysis. EDX spectroscopy depends on the principle that each element has a unique atomic structure resulting in a unique set of peaks on its electromagnetic emission spectrum, which allows for measuring the elemental composition of the specimen [16].

IV. RESULTS

A. Grain size distribution

Table I shows the geometric means of the percentage passing of grain size contents at all different locations. It is found that the maximum percentage passing occurs at locations E, while the minimum value occurs at location F (Figure 3).

B. Mineralogy

The XRD patterns of all samples clearly exhibit the typical phase of Quartz mineral (Figure 4). The quartz is the major mineral with 58 % of the soil sample. In the XRD patterns, the highest peak of $2\Theta = 26.0^{o}$ can be assigned to SiO_2 according to the standard pattern number 46-1045 (JCPDS, 2000). XRD patterns for the other minerals show similar behavior and will be discussed in a future work.

TABLE I. GEOMETRIC MEANS OF % PASSING AT DIFFERENT LOCATIONS

Sieve no	Diameter (mm)	A	B	C	D	E	F	G	Mean (%)
		Locations							
s4	4.75	80.77	89.43	83.8	86.87	90.23	68.38	88.78	83.71
s6	3.35	74.99	85.08	75.72	84.19	85.89	65.35	85.28	79.15
s10	2	66.95	74.8	68.31	73.77	79.25	60.81	78.88	71.54
s18	1	60.12	66.57	62.79	64.94	74.27	52.96	73.53	64.65
s20	0.85	51.76	55.65	53.1	57.67	67.49	45.4	65	56.14
s40	0.43	44.4	46.89	45.75	53.05	61.96	40.26	54.19	49.05
s60	0.25	37.32	40.25	38.29	44.2	53.75	30.56	44.91	40.78
s100	0.15	30.47	34.32	31.57	38.24	46.65	26.3	38.79	34.66
s200	0.08	24.77	27.91	27.74	33.18	41.4	19.8	30.99	28.73

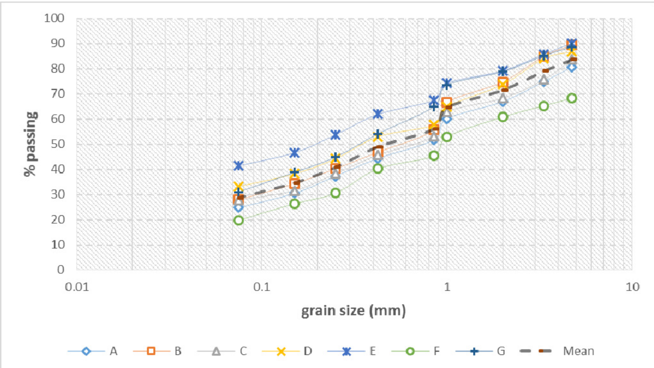

Fig. 3. Grain Size distribution curves of the studied soil samples of the different locations

C. *Element concentrations*

Figure 5 shows major and trace elements of the studied soil samples that were determined by Energy Dispersive X-Ray Analysis (EDX). Table II shows the two major elements (Si, O) contents of Quartz at the different studied locations with an average percentage of 16.4% and 63.96 %, respectively.

D. *Correlation*

To detect and compare the strength and direction of the linear relationships between grain size distributions and the content for each of silicon and oxygen concentrations, the correlation coefficients (r), were calculated using the values of Table III. The values of correlation coefficient (r) between grain size and both silicon and oxygen are plotted in Figure 6. As shown in Figure 6 the correlations increase with grain size for both elements (Si, O) till around 1.0 mm, beyond which the correlations decrease gradually to 0.08 mm. At grain size 0.85 and 1.0 mm, which is the size of medium sand, the sample shows maximum correlation of 0.21% and 0.42 % for silicon and oxygen, respectively. On average, oxygen correlation is 39% higher than that of silicon. For O, the correlations increase from 0.18 at 0.075 mm to 0.42 at 1 mm. Then it drops to 0.15 at 4.75 mm. For Si it increases from 0.01 to 0.20 then drops down to 0.06 at the same grain sizes. The observed deviation is most probably due to the existence of composite quartz grains. Some of quartz grains are stained, coated or locked with other mineral varieties; mainly carbonate.

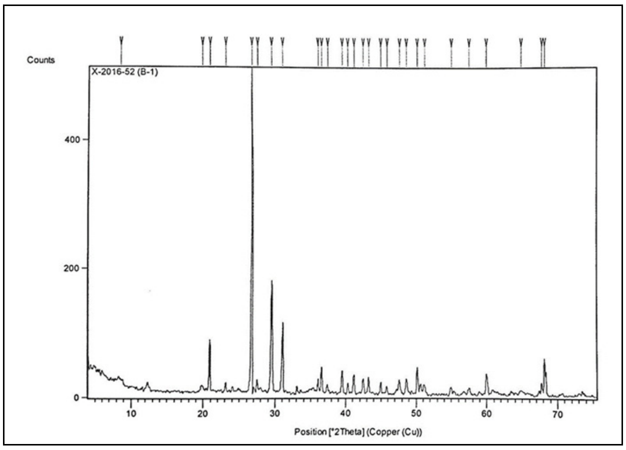

Fig. 4. XRD patterns of the current sample

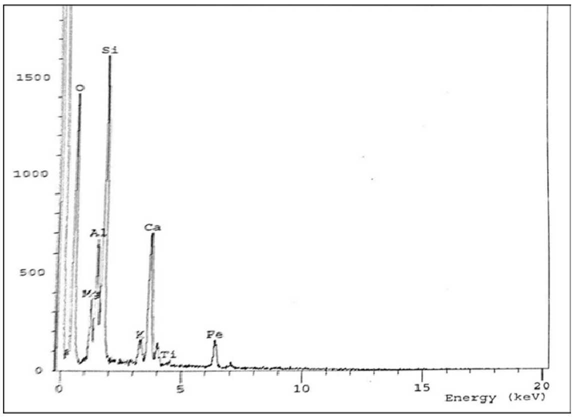

Fig. 5. EDX Spectrum of the current samples

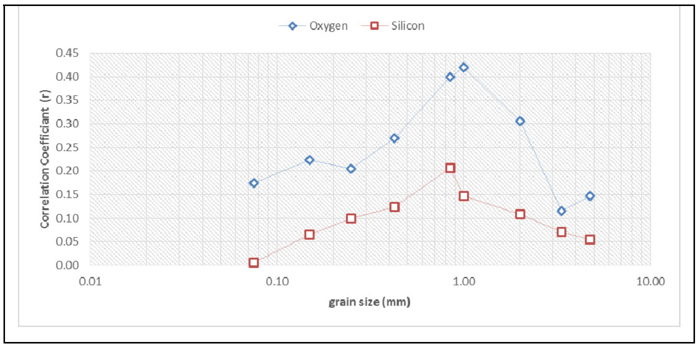

Fig. 6. Relation between correlation coefficient and grain size of Si and O elements

TABLE II. GEOMETRIC MEANS OF INDIVIDUAL SI AND O ELEMENT CONTENTS (%)

Elements	Locations							Mean
	A	B	C	D	E	F	G	%
Silicon (Si)	20.66	13.23	14.73	16.99	15.55	14.8	19.81	16.35
Oxygen (O)	62.94	63.5	64.64	63.26	64.16	64	65.24	63.96

TABLE III. CORRELATION BETWEEN GRAIN SIZE AND ELEMENT (SI, O) CONTENTS

Grain size (mm)	0.08	0.15	0.25	0.43	0.85	1	2	3.35	4.75
Silicon (Si)	0.18	0.22	0.21	0.27	0.4	0.42	0.31	0.12	0.15
Oxygen (O)	0.01	0.07	0.1	0.12	0.21	0.15	0.11	0.07	0.06

E. Polynomial Regression

The relation between grain size and its correlation with silicon and oxygen are fitted with polynomials of degree 2, as follows:

$$Y=-0.0263x^2+0.0938x+0.2338 \qquad (1)$$

for oxygen and by

$$Y=-0.0156x^2+0.0648x+0.0742 \qquad (2)$$

for silicon

Where Y represents the correlation coefficient of the selected element and X represents the grain size in mm.

The values of coefficient of determination (R^2) are 0.40 for oxygen and 0.31 for silicon (i.e. 40% of oxygen and 31% of silicon of data are above the best fit curve). Thus means that strength of the relations are medium.

When the degree of the polynomial has increased to the fourth degree the R^2 values are above 0.90 (Figure 7). The fourth degree polynomial fitting is given by

$$Y=-0.0035x^4+0.0652x^3-0.3472x^2+0.5612x+0.1211 \quad (3)$$

for oxygen and by

$$Y=-0.011x^4+0.1168x^3-0.4077x^2+0.4933x-0.0124 \quad (4)$$

for silicon.

The R^2 values for the 4th degree fitting are 0.96 and 0.91 respectively (Figure 8).

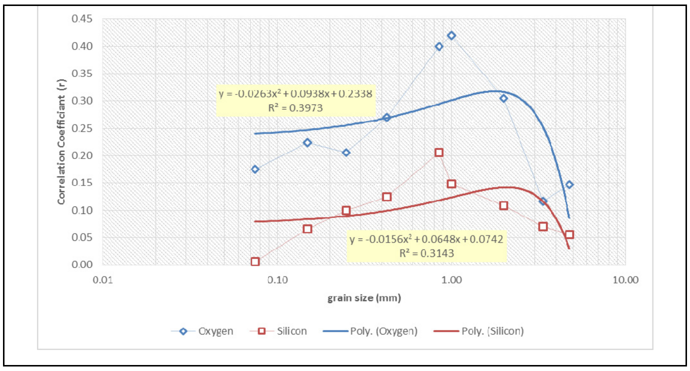

Fig. 7. Second degree polynomial of correlation in grain size

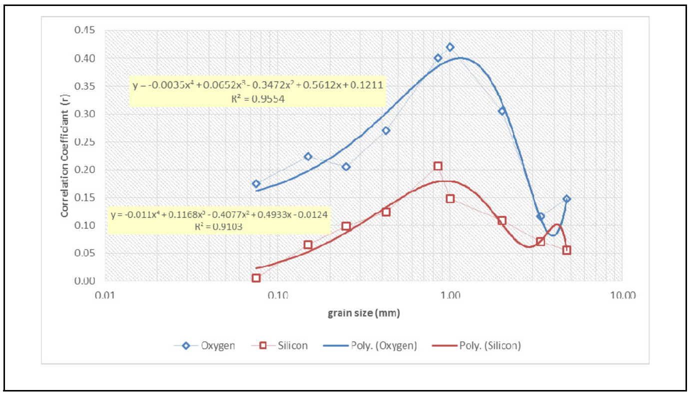

Fig. 8. Fourth degree polynomial of correlation in grain size

V. ELEMENT CONTENTS IN EACH FRACTION

To find the theoretical content of elements that corresponds to each grain size, the values in Table I were multiplied by the values in Table II then divided by 100. Tables IV and V show that content of oxygen and silicon respectively. The mean element content for each element (Tables IV and V) is logarithmically modeled in term of grain size. The fitting for oxygen given by:

$$Y=8.8369\ln(x)+39.5 \qquad (5)$$

For silicon the fitting is given by

$$Y=2.2586\ln(x)+10.096 \qquad (6)$$

Where Y represents element content percentages and X the grain size (mm)

TABLE IV. OXYGEN IN EACH FRACTION

Size (mm)	Locations							Mean (%)
	A	B	C	D	E	F	G	
4.75	50.83	56.78	54.17	54.95	57.89	43.76	57.93	53.54
3.35	47.19	54.02	48.95	53.26	55.11	41.82	55.64	50.63
2	42.13	47.49	44.16	46.66	50.85	38.92	51.46	45.76
1	37.84	42.27	40.59	41.08	47.65	33.89	47.98	41.35
0.85	32.58	35.34	34.33	36.48	43.3	29.06	42.41	35.9
0.425	27.94	29.77	29.57	33.56	39.76	25.76	35.36	31.37
0.25	23.49	25.56	24.75	27.96	34.49	19.56	29.3	26.08
0.15	19.18	21.79	20.41	24.19	29.93	16.83	25.31	22.17
0.075	15.59	17.72	17.93	20.99	26.56	12.67	20.22	18.38

TABLE V. SILICON CONTENT IN EACH FRACTION

Size (mm)	Locations							Mean (%)
	A	B	C	D	E	F	G	
4.75	16.69	11.83	12.34	14.76	14.03	10.12	17.59	13.68
3.35	15.49	11.26	11.15	14.3	13.35	9.67	16.9	12.94
2	13.83	9.9	10.06	12.53	12.32	9	15.63	11.69
1	12.42	8.81	9.25	11.03	11.55	7.84	14.57	10.57
0.85	10.7	7.36	7.82	9.8	10.49	6.72	12.88	9.18
0.425	9.17	6.21	6.74	9.01	9.63	5.96	10.74	8.02
0.25	7.71	5.33	5.64	7.51	8.36	4.52	8.9	6.67
0.15	6.3	4.54	4.65	6.5	7.25	3.89	7.69	5.67
0.075	5.12	3.69	4.09	5.64	6.44	2.93	6.14	4.7

Both elements reflect a positive relation between their contents and grain size. The ratio of silicon content is a quarter of oxygen contents. With the increase of grain size content a diversion was observed between both elements (Figure 9).

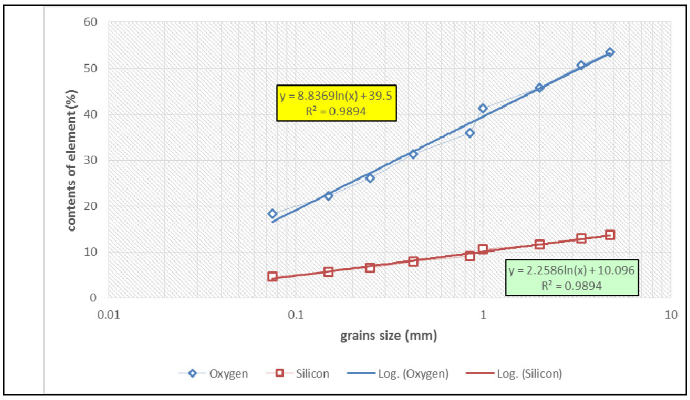

Fig. 9. Relation between grain size and individual Si and O element contents

VI. CONCLUSION

The basic conclusions of this paper as as follows:

- Quartz represents the major mineral in Wadi Arar.
- Oxygen and silicon are the major elements in Wadi Arar.
- The maximum correlation between grain size and element content appears at a grain size of 1.0 mm.
- The max correlation between grain size and oxygen is double of that with silicon (0.42 and 0.21 respectively).
- The strongest relation between grain size and its correlation with element content is a fourth degree polynomial.
- The relation between element content (Si, O) and grain size is a positive and logarithmic relation.

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