

# Evaluation of White Silica Sands in North Eastern Desert, Egypt

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**Abstract**— There are about sixteen occurrences of white silica sand in Egypt; however there is no self-sufficiency in white silica sand for hydraulic fracturing, water filtration and some other industrial applications due to the lack of integrated evaluation. Also many workers have been conducted for the up-grading of white silica sand. Nevertheless, most of these workers evaluate and beneficiate these sands as glassmaking sand only, therefore the main objective is to characterize white silica sand from north eastern desert of Egypt and finds out its possible industrial applications. Twenty six representative sandstone samples as well as three head samples were collected from three sections along the study area from Wadi Qena and Somr El- Qaa formations to carry out an integrated evaluation, which includes a whole range of laboratory tests and analytical procedures to study the physical, the mineralogical, and the geochemical properties. The characterization reveals that the grain size distribution, grains morphology, mineral and chemical composition of the studied samples are suitable for the specification of many industries such as glassmaking, abrasive, water filtration, building products, chemicals and Semiconductors industries; as dug or with some essential beneficiation processes such as sizing and classification to produce the required size gradation, attrition scrubbing or chemical leaching to iron oxide-clay coating removal and flotation to heavy mineral elimination.

**Index Terms**— White silica sands, Grain size analyses, Digital image analysis, Heavy minerals, Petrography, Diagenesis, Geochemistry

## 1 INTRODUCTION

The white silica sands is defined as high purity sands in which the sand grains are made entirely of quartz. Impurities are very minor and commonly are minerals or organic constituents such as clay minerals, iron oxides, feldspars, carbonates, micas, heavy minerals (zircon, tourmaline) and coal [1]. Silica sands have got the most diversified use among all the non-metallic deposits. Silica is a basic material in the glass industry, ceramic and refractory industries, silicon-based chemicals and other miscellaneous uses. Silica sand is evaluated for industrial use on the basis of its composition and physical properties. The specifications for these properties vary according to the use to which the sand is to be put. Chemical composition is of paramount importance in glass-making, whereas grain angularity and hardness are important for sandblasting.

There are about sixteen occurrences of white silica sand in Egypt; the most important locations are Wadi Qena and Wadi El- Dakhl (commercially known as El-Zaafarana). Both are located in the Eastern Desert, Gebel El- Gunnah (south Sinai) and El- Maadi, which is located in the Cairo suburbs as showing in fig.1. There are two main locations in Egypt having high quality of silica sands, the first location lies at Zaafrana area (Wadi Dakhl) and the second one locates at north and south Sinai [2]. White silica sands constitute most of the Wadi Qena Formation [3] and are exposed in an area of approximately 450 km<sup>2</sup> at the western margin of the northern part of Wadi Qena. The quantity of sand available is enormous. According to Omayra [4] the probable reserves were estimated to be about one billion metric tons (Gt). About 50 m of Somr-El Qaa for-

mation mined as glass sand at Wadi Dakhl [3].

The chemical, mechanical and physical characteristics of white sands were studied by many authors for glass industry, e.g. [5], [6], [7] and others. Never the less, most of these workers evaluate and beneficiate these sands as glass making sand only using multiple process routes. Therefore the main objective is to evaluate the quality of the silica sand and the kaolinitic sandstone samples from north eastern desert of Egypt, and Finds out its possible industrial applications.

The study area is located in the North Eastern Desert, bounded in the north by Wadi Dakhl, and extends southward to the central part of Wadi Qena between Longitudes 032° 08' to 033° 06' and Latitudes 27° 22' to 28° 43' "Fig.1". This area was chosen for its proximity to the export harbors on the Red Sea and Suez Canal region. Egypt's geographic location in the center of the silica sands global market, qualify it to be the center of the production and exportation of silica sand Products.



Fig.1. Location of the study area and main occurrences of white silica sand in Egypt, modified after [5]

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## 2 MATERIALS

Three head and twenty six representative white silica sand samples were collected from three sections along the study area "table 1". These samples represent the Wadi Qena and Somr El-Qaa Formations. Wadi Qena Formation sandstones samples mainly have a similar lithological characteristic. They are commonly creamy white color and bonded with kaolin. They are very fine- to- very coarse grained, and characterized by poorly to moderately sorted, subangular to subrounded, and moderately-hard to semi-friable. They have specific gravity ranging from 2.35 to 2.38g/cm<sup>3</sup>, moisture content less than 0.1% and occasionally contain coarse sand and gravel. A thickness of Somr El Qaa Formation is about 50m; it mined as glass sand at Wadi Dakhl. It is mainly medium to coarse grained, and characterized by moderately- to- well- sorted, subangular to subrounded, and semi-friable to friable. It has specific gravity equal to 2.46g/cm<sup>3</sup>, moisture content less than 0.09%. It is characterized by white to reddish white color, and it is weakly cemented with silica and hematite.

TABLE 1  
LOCATIONS, GEOGRAPHICAL COORDINATES, LITHOLOGY, AGE AND HEAD SAMPLES OF STUDIED SECTIONS

Location	Latitude Longitude	Formation	Age	Lithology	Head sample
Wadi Qena	27° 41' 53.9" 032° 36' 07.2"	Wadi Qena	Early Cretaceous to Cenomanian	Kaolinitic sandstone	HS1
	27° 59' 03.7" 032° 30' 48.6"				HS2
Wadi Dakhl	28° 40' 54.3" 032° 26' 35.2"	Somr-El Qaa	Carboniferous	Silica sand	HS3

## 3 METHODS AND TECHNIQUES

### 3.1 Particle size analysis techniques

The studied deposits samples were subjected to dry and wet sieving analysis, while head samples of kaolinitic sandstones subjected also to sieving after liberation of grains using attrition scrubbing. About 200 gm from each sample for each test were used. The dry sieving test was carried out using Ro-Tap. A time was set of 20 minutes with high shaking power. The particle size distribution was determined using a set of sieves of aperture sizes of 4750, 2000, 1180, 1000, 850, 600,500, 425, 300, 250, 180, 90, and 80µm. Hydrometer technique is used for mud size fraction analysis; it is conducted according to AASHTO, T27-11 designations [8].

### 3.2 Digital image analyses method

Digital image analysis method has been used to determine particle shape parameters using transmitted light Polarizing microscope is named GX-microscope model NPL-400B, equipped with digital camera which named HDCE-X5 and has a 5 megapixel resolution. The software application is ImageJ (FIJI 1.46), a public domain Java image processing and analysis program inspired by NIH Image.

### 3.3 Mineralogical and petrographical techniques

The X-Ray Diffraction (XRD) technique was used as a semi-quantitative mineralogical tool (i.e., mineral in a quantity of <5% in a sample is not clearly detectable) to identify the mineral components. The Scanning Electron Microscope (SEM) technique was used to visualise the shape, size, texture

and morphology of the particles" surfaces and examine the fine clay fractions. Heavy minerals analysis accomplished by gravity method using the dense liquid "Bromoform". To determine relative abundance of heavy minerals in a sample, fleet method [9] was used.

### 3.4 Chemical analysis techniques

X-Ray Fluorescence (XRF) spectrometry was used to determine the chemical composition of major and some trace elements of the whole samples and their size fractions.

## 4 RESULTS AND DISCUSSION

### 4.1 Grain size analysis

#### 4.1.1 Sieve analysis

Dry, wet and after attrition sieving of the kaolinitic sandstone head samples (HS1 and HS2) showed that the pan fractions in the sieving after attrition scrubbing are 13.04 and 15.13% respectively. The pan fractions in wet sieving are 10.24 and 10.15% respectively. Also the pan fractions in dry sieving are 5.88 and 5.88% respectively. The pan fractions in the sieving after attrition scrubbing had the greatest value compared to the other two methods. This greatest value could be explained due to the washing of the clay material from the surface of the grains and dissociation of the lumps "fig.6 and 7". So the sieving after attrition scrubbing gives true and more representative grain size distribution for kaolinitic sandstone samples. While the completely liberation of the individual grains of silica sand sample is easily attained by hand crushing "fig.8". In this case the mud fraction was less than 0.07 wt%, so that the dry sieving is sufficient to give true and more representative grain size distribution "Fig.3 and table 2".

The coefficient of uniformity "Cu" of the three head samples, no. HS1, HS2 and HS3, is about 4.09, 7.36 and 2.6 respectively. The coefficient of concavity "Cc" of HS1, HS2 and HS3 is about 1.98, 4.09 and 1.2 respectively. So the kaolinitic sandstone head samples (HS1 and HS2) are well graded, while silica sand head sample (HS3) is poorly graded. The median size (d<sub>50</sub>) of HS1, HS2 and HS3 samples is 220µm, 222µm and 365µm respectively, which indicates that the studied sand samples are mainly medium-grained size.

TABLE 2  
WET, DRY AND AFTER ATTRITION SCRUBBING (ATT. S) SIEVING ANALYSES RESULTS OF HEAD SAMPLES

Sieve size(µm)	samples						
	HS1			HS2			HS3
	Dry	Wet	Att. s	Dry	Wet	Att. s	Dry
	Weight retained %						
4750	1.54	0.07	0.03	0.27	0.00	0.00	0.00
2000	0.62	1.24	0.47	1.24	0.42	0.12	0.20
1180	1.45	1.13	0.43	4.53	2.32	0.12	1.66
1000	0.57	0.49	0.29	1.23	0.64	0.02	0.86
800	1.70	1.55	0.92	2.30	1.77	0.03	3.02
600	5.96	6.06	5.51	4.27	3.33	0.67	11.17
500	2.51	2.24	2.69	1.34	1.13	0.70	6.13
425	0.04	0.02	0.15	0.05	0.03	0.05	0.03
300	28.94	27.07	26.71	17.15	14.01	12.55	43.31
250	0.69	0.45	2.31	0.53	1.18	1.87	2.45
180	42.28	41.64	36.80	54.27	54.17	59.79	29.99
150	1.22	0.33	1.33	0.21	0.81	1.25	0.22
125	0.97	4.03	5.20	4.11	6.39	4.19	0.49
90	5.23	2.69	3.22	1.92	2.95	2.80	0.28
80	0.41	0.77	0.89	0.69	0.70	0.72	0.12
pan	5.88	10.24	13.04	5.88	10.15	15.13	0.07
total	100.00	100.00	100	100.00	100.00	100	100

HS1, HS2 and HS3 samples contain about 77, 83.5 and 76.5% for respectively of sands in the grain size fraction of 500-90 $\mu$ m. These facts should be taking into consideration in any next upgrading stage.

**4.1.2 Hydrometer analysis**

In sieve analysis after attrition scrubbing, the -80 $\mu$ m size fraction of HS1 and HS2 head samples are about 13.04 and 15.13 wt% respectively. This fine material (-80 $\mu$ m) was analysed to determine the particle size distribution using hydrometer technique. The results have shown that 65% of the fine material of HS1 having diameter less than 45 $\mu$ m and 22.5% of this fine materials having diameter less than 5 $\mu$ m, which stands for 8.47% and 2.93% of the whole sample respectively. While the -45 $\mu$ m size fraction of HS2 is about 71% and the -5 $\mu$ m size fraction is about 16.5%, which stands for 10.74% and 2.49% of the whole sample respectively, see fig.2 and table 3.

**4.1.3 Compatibility of grain size distribution with the industrial specifications**

As dug; the studied sands grain size range or gradation does not meet the required industrial specifications of many industries such as glass industry, and needs to be classified and sized to meet these specifications. However the particle size distributions reveal that the size composition of the studied sands is suitable for the specifications of many industries with different percentages, where more than 77% of HS1, 83.5% of HS2 to 76.5% of HS3 grains fall mainly in the 0.5 to 0.090mm size grades (glassmaking sand's size range). This size composition is suitable for the production of all kinds of glass according to specifications of the British [10] and Indian standards [11]. About 16% of HS1, 4% of HS2 and 33% of HS3 grains fall in the abrasive sand size range and about 79.5% of HS1, 85.25% of HS2 and 96.5% of HS3 grains fall in the foundry sand size range. In addition about 76.65% of HS1, 76.70% of HS2 and 99.25% of HS3 grains fall in the hydraulic fracturing (Frac) sand size range and about 8.5% of HS1, 1.5% of HS2 and 20% of HS3 grains fall in the filter media sand size range [12] "Fig.3".

TABLE 3

HYDROMETER ANALYSIS RESULTS OF KAOLINITIC SANDSTONE HEAD SAMPLES

HS1		HS2	
Grain size ( $\mu$ m)	Finer (%)	Grain size ( $\mu$ m)	Finer (%)
80.00	100.00	80.00	100.00
58.75	68.00	57.69	71.10
42.09	64.00	41.62	67.10
29.83	63.00	29.49	64.10
19.11	60.00	19.03	62.00
11.31	53.00	11.10	58.00
6.86	39.50	6.71	44.00
4.46	19.00	4.53	13.50
1.88	7.00	1.88	8.00
1.34	4.40	1.31	6.00

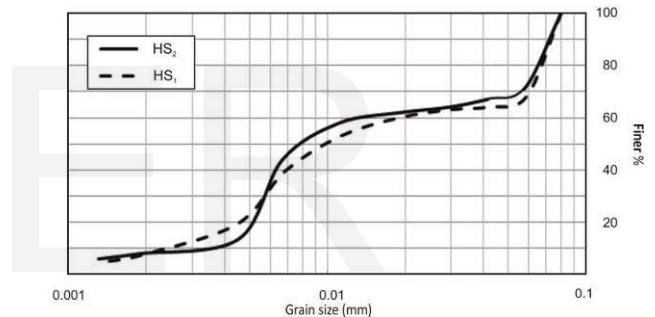


Fig.2. Distribution curve of the (-80 $\mu$ m) size fraction of kaolinitic sandstone head sample

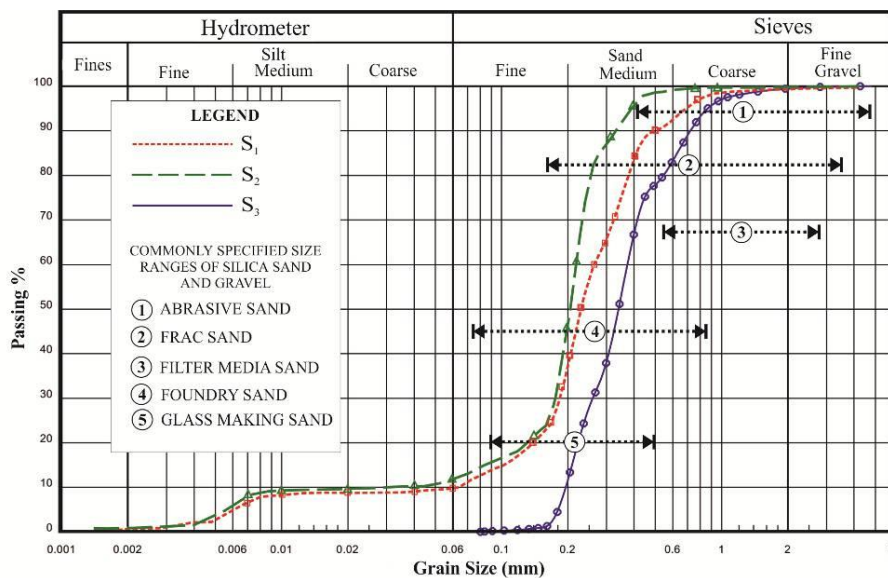


Fig.3. Grain size distribution curves of head samples and commonly specified size range of industrial applications

### 4.2 Grain morphology

In digital image analysis method and for head samples HS1 and HS2, three size fractions were used. These fractions were 0.090-0.180mm, 0.180-0.300mm, 0.300-0.600mm, and over 0.600mm. But in case of HS3 head sample, the size fractions were 0.090-0.180mm, 0.180-0.300mm, 0.300-0.500mm, and over 0.500mm. The Pictures were captured on sieved and clean sand. Twenty randomly selected particles were examined; each particle graded on Roundness, Sphericity, Aspect Ratio (AR) and Solidity. The arithmetic mean calculated for each characteristic.

#### 4.2.1 Grain shape parameters

The morphological study results of the HS1, HS2 and HS3 head samples showed that; the average circularity and angularity of HS1 head samples size fractions ranges from about 0.75 to about 0.77 (high circularity) and from about 0.24 to 0.39 (angular-sub-angular) respectively; HS2 head samples size fractions ranges from about 0.72 to about 0.81 (high circularity) and from about 0.31 to 0.43 (sub-angular-sub-rounded) respectively; HS3 head samples size fractions ranges from about 0.70 to about 0.80 (high circularity) and from about 0.38 to 0.54 (sub-rounded), respectively "table 4".

#### 4.2.2 Compatibility of grain shape parameters with the industrial specifications

Particle shape is an important factor in evaluating sand for several uses. The shape of the quartz particles is important as it affects the melting characteristics in glass making; if the particles are too needle-like they will not melt uniformly (the ends of the needles melt first) [1]. All studied size fractions of Wadi Qena kaolinitic sandstone samples (HS1 and HS2) and of Somr El-Qaa silica sand (HS3) have relatively homogenous grain shape parameters, so that the studied sands meet the required specification of glassmaking sand. Figure (4) shows plot of the averages circularity and angularity on folk's comparison chart of Sphericity-roundness. The studied sands meet the required specification for blasting sands as both rounded and angular sand grains are used in sand blasting work. Rounded grains are more commonly used, for they produce smoother surfaces and are more durable [1].

The circularity and angularity of HS1 and HS2 sand samples does not meet the required specifications for hydraulic fracturing sands, generally sand for use in hydraulic fracturing should have a roundness and circularity factors of 0.6 or more as shown in fig.4. But it is possible for Somr El-Qaa silica sand (HS3) to up-grade with some essential adjustments to meet these specifications by Coating with resin, which could improve the roundness and sphericity of sand particle. Resin could provide better resistance for the sand on high closure stress. Furthermore, resin-coated sand can reduce the proppant flow back problem that can cause the fracture to close and reduce the permeability [13], or it can be upgrade using attrition scrubbing under high solid ratio.

### 4.3 Mineralogical study results

#### 4.3.1 XRD analyses

The results of the mineral identification and the semi-quantitative XRD study are presented in table 5. The XRD

results of the kaolinitic sandstones samples (HS1 and HS2) indicated that the quartz and the Kaolin clay mineral were found as major constituents. While the results of the silica sand sample (HS3) indicated that the quartz was only the major mineral constituent.

TABLE 4  
GRAIN SHAPE PARAMETERS OF HEAD SAMPLES SIZE FRACTIONS

Sample	Size fraction	Grain shape parameters			
		Circularity	Angularity	Aspect ratio	Solidity
HS1	+90-180	0.77	0.24	1.33	0.94
	-180+300	0.75	0.39	1.37	0.96
	-300+600	0.75	0.34	1.36	0.96
	+600	0.76	0.39	1.33	0.97
HS2	+90-180	0.72	0.31	1.43	0.93
	-180+300	0.74	0.42	1.39	0.95
	-300+600	0.81	0.39	1.25	0.96
	+600	0.80	0.43	1.27	0.97
HS3	+90-180	0.70	0.38	1.46	0.92
	-180+300	0.80	0.40	1.27	0.96
	-300+500	0.73	0.38	1.42	0.96
	+500	0.76	0.54	1.35	0.98

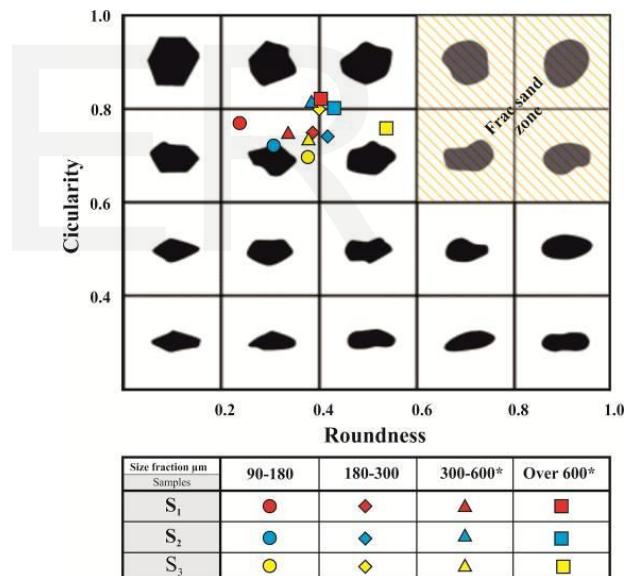


Fig.4. Plot of the averages circularity and roundness of studied size fractions on Sphericity-roundness comparison chart [14] and hydraulic fracturing sand circularity /roundness specification (Fracsand zone)

TABLE 5  
MINERALOGICAL AND SEMI-QUANTITATIVE XRD RESULTS

Sample	Semi-quantitative XRD study results (%)	
	Quartz	Kaolin
HS1	89.0	11.0
HS2	82.5	17.5
HS3	100	0.0



### 4.3.2 Heavy minerals analyses

The heavy minerals study was conducted on the heavy minerals of the Glass Sand Fraction of HS1, HS2 and HS3 head samples. This is due to the fact that heavy mineral contaminant specifications for Glass making Sand are more rigorous than those associated with other industrial application. The subsamples used in the study are the size fractions of 600-300, 300-180 and 180-90 μm for HS1 and HS2, and the size fractions of 500-300, 300-180 and 180-90μm for HS3 head samples.

The results showed that the heavy minerals percentage mainly increases as the grain size decreases. The total weight percentage of the heavy minerals in the studied fractions (500 or 600-90 μm) was found to be 0.036% for the silica sand sample HS3 and 0.05 to 0.06% for the kaolinitic sand samples (HS1 and HS2). Thus, the amount of the heavy minerals found in both deposits was very little, and their removal will not show high improvement with regard to chemical composition in any subsequent processing stage. Relatively, the total weight percentage of the heavy minerals in the studied size fractions of the kaolinitic sandstone samples was found more than that of the silica sand sample.

In Somr El-Qaa sample (HS3) about 43% of heavy mineral content concentrated in the -180μm size fraction, which represent only about 1.2% of -500μm size fraction. As well the -180μm size fraction of HS1 sample contain about 95% of heavy mineral contaminants, which represent about 13% of -600+90μm size fraction. So that the screening can be used to reduce the heavy minerals content or to reduce the weight percentage of the size fraction which may be subjected to heavy mineral separation process, if there is a subsequent stage of the chemical leaching to use the sand for high technology industry (SiO<sub>2</sub> ≥ 99.95%), as the heavy minerals slightly affected during chemical leaching.

The heavy mineral analysis reveals the presence of opaque and non-opaque minerals. Opaque minerals are represented by anhedral to subhedral grains. They are composed essentially of magnetite, hematite, ilmenite, limonite, leucoxene and pyrite. Opaque minerals reach in abundance more than 40% in most samples, magnetic fraction range from 1.49 to about 3.13%. Non-opaque minerals constitute the main

bulk of the heavy mineral suite as they reach in abundance more than 51% in most samples. Three major non-opaque heavy minerals (tourmaline, zircon, and rutile) were identified and counted separately, Some heavy minerals such as apatite, straulite, sillimanite, chlorite, and monazite were also recorded, but in very lesser amounts (less than 2.42%), counted together as (other minerals) "Table 6". In general the ultrastable heavy minerals supersede the metastable heavy minerals. Figure (5) shows some micrographs of main bulk heavy minerals and their descriptions.

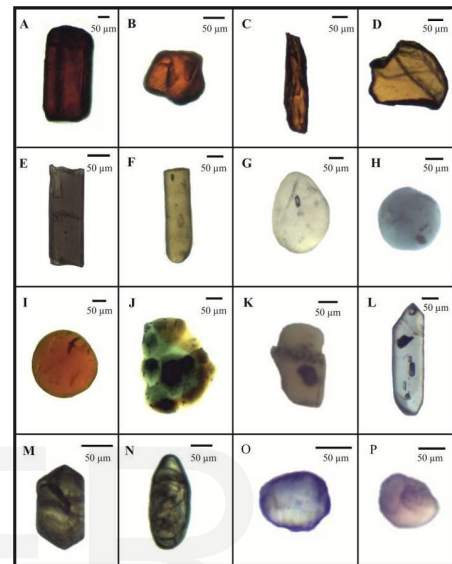


Fig.5. Heavy mineral micrographs (all micrographs are in plane polarized light). Rutile: prismatic deep red with subrounded edge (A), blood red subspheric (B), elongated(C); irregular brownish red (D); Tourmaline: prismatic brown euhedral termination (E); prismatic light brown with one rounded edge (F); oval colorless with prismatic zircon inclusion (G); rounded blue with inclusion (H); rounded reddish brown (I); irregular brownish green and green zoned colors; subhedral brown with rutile inclusion (J); Zircon: prismatic euhedral colorless with inclusions (L) brown with zoning (M) and rounded overgrowth (N); spherical and well rounded colourless (O) pink (P).

TABLE 6  
RELATIVE ABUNDANCE AND PERCENTAGE OF HEAVY MINERALS IN EACH SIZE FRACTIONS OF HS1, HS2 AND HS3 HEAD SAMPLES

sample	Heavy mineral distribution (wt %)				Heavy minerals relative abundance (%)					
	Size fraction (μm)				Opaque		Non-opaque			
	600/500-300	300-180	180-90	Total	Non-Magnetic	Magnetic	Tourmaline	Zircon	Rutile	Other
HS1	0.003	0.002	0.378	0.05	49.46		27.373	17.543	3.871	1.751
					46.87	2.59				
HS2	0.019	0.052	0.190	0.060	47.21		36.063	7.856	7.521	1.35
					44.73	2.47				
HS3	0.009	0.037	1.237	0.037	40.02		33.43	18.79	5.33	2.42
					37.92	2.1				

#### 4.4 Petrographical study

Twelve representative thin sections were examined from both Wadi Qena and Somr El-Qaa Formations using transmitted light polarizing microscope attached by digital camera. The examination revealed that the sandstones of Wadi Qena and Somr El-Qaa Formations can be classified into two main petrographic groups: quartz arenites and quartz wackes following the classification of Tucker [15].

The Sandstone of Wadi Qena dominated by quartz wackes, varies from very fine- to very coarse-grained and from poorly- to moderately- sort with angular to subrounded grains. The detrital mode is characterized by the removal of all mineral except quartz, mica (concentrated in-80 $\mu$ m size fraction) and refractory accessory minerals (e.g. tourmaline, zircon, and rutile) with rare rock fragments "Figs.9.A-to-L". X-ray diffraction analysis showed that the kaolin is only clay mineral species detected in the Wadi Qena Formation sandstones. Kaolin occurs in almost all the studied samples. The presence of both amorphous and crystalline phases of kaolin give an indication to detrital origin of kaolin which undergoes considerable crystallization during diagenesis of long duration or worm-like crystals "Fig.9.F".

Compaction, cementation, dissolution, replacement and recrystallization are the most important diagenetic features noticed in the sandstones of Wadi Qena Formation. Compaction effects are expressed by three to four contacts per grain and fractured quartz grains "Fig.9.G". Cementing materials include clay minerals "Fig.8.E and F", iron oxides and calcite cements "Fig.9.D". Kaolin is the most abundant, calcite is the second most abundant cements, and it was probably formed from meteoric water at shallow burial. Fe oxide cements represented by hematite and limonite. Hematite occurred as cementing material and/or spots "fig.8.K", grain coating, patches filling pore spaces or intergrown with clays. Iron was probably released by the alteration of magnetite and other Fe bearing minerals. Kaolin cement /matrix and quartz grains dissolved and replaced with calcite cement "Fig.9.J and L", dissolution process have led to secondary porosity. Calcite cement is suffered from dissolution process as indicated by the presence of moldic pores rimmed by calcite cement with an irregular outline "Fig.9.H".

The Sandstone of Somr El-Qaa Formation dominated by quartz arenites, varies from fine- to very coarse-grained and from moderately to very well-sorted with subrounded grains, cemented with silica. The detrital mode is also characterized by the removal of all mineral except quartz and refractory accessory grains (e.g. tourmaline, zircon, and rutile) with rare rock fragments "Figs.9.M-to-P". It is characterized by quartz wacke, fine to medium grained, subangular to subrounded, and well bonded with kaolinitic matrix. X-ray diffraction analysis showed that kaolinite is only clay mineral species detected. Quartz wacke represents only about 5m thickness of the 50m studied section.

Compaction, cementation, hematite pigmentation, dissolution and replacement are the most important diagenetic features noticed in the sandstones of Somr El-Qaa Formation. The studied quartz arenites exhibit pressure solution features including concavo-convex contacts "Figs.9.N" and less

commonly sutured contact. The compaction of the detrital framework has resulted in close packing which has caused a reduction in porosity. Cementing materials include silica cement "Figs.9.N and O", iron oxides "Figs.9.O", and calcite cements. Silica is the most abundant cements; hematite is the second most abundant. The studied quartz arenites is poorly cemented and very friable. Silica cementation acts as secondary enlargement of the quartz grains forming optically continuous overgrowths which result in euhedral crystals. The dissolved silica originated from the effective pressures exerted at the contact between quartz grains and this has enhanced the solubility at these points. Hematite occurred as cementing material and/or spots, grain coating and Patches filling pore spaces "Figs.9.O and P". Iron was probably released by the alteration of magnetite and other Fe bearing minerals. Silica cements, quartz and refractory accessory grains dissolved partially and replaced with hematite cement. Silica solution and hematite replacement were controlled by changes in pH, and temperature "Figs.9.O and P",

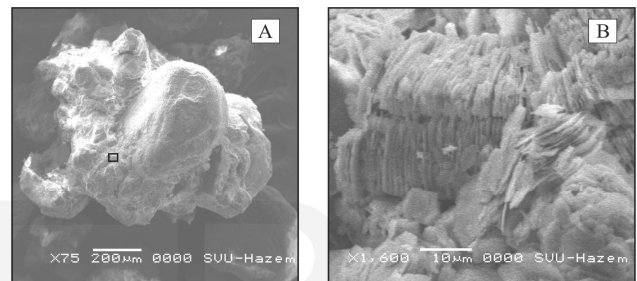


Fig.6. SEM photographs: "A" shows lump of sand grains bounded with kaolinite after wet sieving for HS2 head sample. "B" shows pseudo hexagonal plates of kaolinite (Field of view is shown in "A")

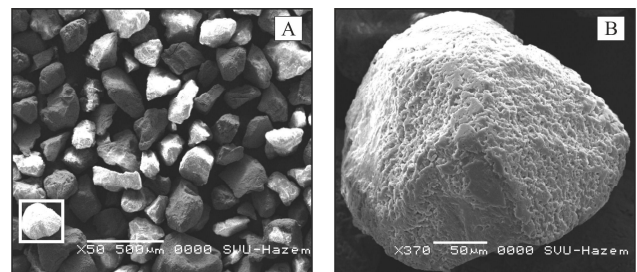


Fig.7. SEM photographs: "A" shows the completely liberated -2000 $\mu$ m size fraction of HS2 head sample after attrition scrubbing. "B" shows the clay coating on quartz grain which not responded to attrition scrubbing (Field of view is shown in "A").

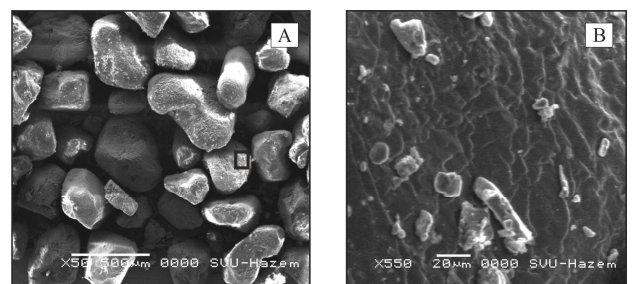


Fig.8. SEM photographs: "A" shows the completely liberated dry sieved -2000 $\mu$ m size fraction of HS3 head sample. "B" shows fine mineral particles on the surface of sand grain (Field of view is shown in "A").



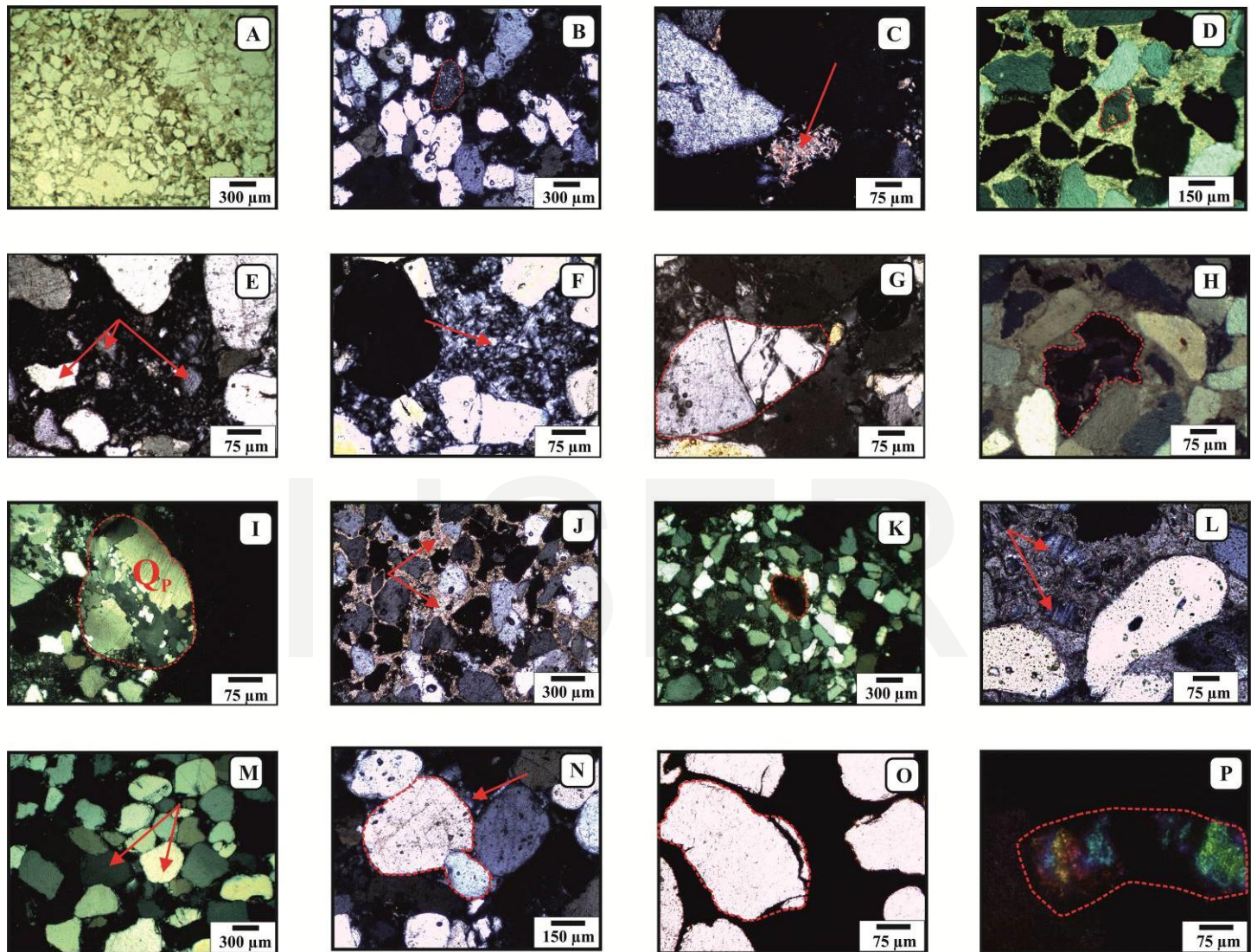


Fig.9. Photomicrograph (A and O Photomicrographs are in plane polarized light, where the other Photomicrographs are in cross polarized light) of Wadi Qena (A to L) and Somr El-Qaa Formations sandstones (M to P) shows: (A) Quartz wacke, fine to medium grained, subangular to subrounded, moderately well sorted, and well bonded with kaolinitic matrix; (B) Lithic fragment (chert); (C) Minute crystals of Calcite cement; (D) Monocrystalline quartz (Qm) grain has inclusion of tourmaline. (E) Quartz grains completely enclosed by kaolinitic matrix (see arrows); (F) Recrystallized kaolin worm-like crystals from amorphous phase; (G) Fractured monocrystalline quartz grain; (H) Calcite cement is suffered from dissolution process as indicated by the presence of moldic pore rimmed by calcite cement with an irregular outline; (I) Polycrystalline quartz grain (Qp) displaying a bimodal size distribution of subcrystals (note: undulose extinction); (J) Well cemented quartz arenite by calcite cement; (K) Hematite cement occurred as spot; (L) Kaolin worm-like crystals dissolved and replaced with calcite cement (see arrows); (M) quartz arenite, medium to coarse grained, subrounded, moderately well sorted and cemented with silica; (N) concave convex contact and microcrystalline quartz cement fill up the interstitial space between quartz grains (see arrows); (O) Silica overgrowth corroded and dissolved, and partially stained and replaced by the second generation of hematite cement; (P) Refractory accessory mineral grain (Zircon) dissolved partially and replaced with hematite cement.

#### 4.5 Geochemical study

The chemical analysis for the major standard elements "Si, Al, Fe, Ti, Na, Ca, Mg, Mn, K, P" and some trace elements was carried out using X-Ray Fluorescence "XRF" method for the whole sample and the size fractions of the silica sand and the kaolinitic sandstone samples.

##### 4.5.1 Wadi Qena Formation

The results of the chemical analysis "Table 7" for the whole head samples HS1 and HS2 of Wadi Qena Formation revealed that the proportions of SiO<sub>2</sub> ranged from 85.514 to 81.284%; of Al<sub>2</sub>O<sub>3</sub> from 11.98 to 13.595%; of Fe<sub>2</sub>O<sub>3</sub> from 0.104 to 0.104%; and of TiO<sub>2</sub> from 0.192 to 0.369%.

The completely liberation of the individual grains of kaolinitic sandstone samples is not easily attained using dry or wet sieving and they are not sufficient to remove the clay fraction which sticks on the grain surface especially angular grains "Fig.6 and 7". It is only attained using attrition scrubbing. It is conducted for three minutes, with 70% solid density, followed by wet screening using 600, 90 and 45µm screens to obtain four size fractions; -0.045 mm, +0.045 to -0.090 mm, +0.090 to -0.600 mm and +0.600 to 2.000mm. These size fractions selected based on sieve and heavy mineral analysis results. Chemical analysis of HS2 sample size fractions showed that; the best results obtained was within the size fractions of 600 to 90µm in terms of higher silica (98.168 wt.%) content and lower content of other oxides i.e. Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, and Fe<sub>2</sub>O<sub>3</sub> content "Table 7". The results indicated that the TiO<sub>2</sub>, ZrO<sub>2</sub>, and Fe<sub>2</sub>O<sub>3</sub> were concentrated into -0.045mm size fraction, as free minerals or association with phyllosilicates minerals.

##### 4.5.2 Somr El-Qaa Formation

The results of the chemical analysis for the whole head sample of Somr El-Qaa Formation HS3 revealed that the proportions of SiO<sub>2</sub> ranged from 87.56 to 95.11%; of Al<sub>2</sub>O<sub>3</sub> from 3.39 to 9.83%; of Fe<sub>2</sub>O<sub>3</sub> from 0.01 to 0.09%; and of TiO<sub>2</sub> from 0.09 to 0.36%"Table 8".

The completely liberation of the individual grains of silica sand samples is easily attained by hand crushing "Fig.8", so the dry sieving is sufficient to liberate size fractions using 2, 0.8, 0.5 and 0.18mm screens to obtain four size fractions, less than 0.18 mm, +0.18 to -0.5mm, +0.5 to -0.8mm and +0.8 to 2mm whose selected to be chemically analyzed. The chemical analyses have shown variation in the chemical composition "Table 8". Variation was obvious in the silica, alumina, titania and the iron contents along the chemical composition of all size fractions. This variation relates to the variation of the clay contents and the fine particles of heavy minerals present in the sample, which increases with size decreasing. It was noticed, from the chemical composition of all the sieved size fractions that; The TiO<sub>2</sub>, ZrO<sub>2</sub>, and Fe<sub>2</sub>O<sub>3</sub> were concentrated into the -180µm size fraction. The silica content increased relatively with grain size increasing and the best results obtained was within the size fractions of 2000 to 800µm in terms of higher silica content and lower content of other oxides i.e. Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, and Fe<sub>2</sub>O<sub>3</sub> content.

TABLE 7

CHEMICAL ANALYSIS RESULT OF KAOLINITIC SILICA SAND HEAD SAMPLES AND SIZE FRACTIONS OF HS2 SAMPLE

Size (µm)	Whole head sample		HS2 size fraction (µm)				
	HS1	HS2	+2000	-2000+600	-600+90	-90 +45	-45
SiO <sub>2</sub>	85.514	81.284	---	96.855	98.168	79.513	46.959
Al <sub>2</sub> O <sub>3</sub>	11.890	13.595	---	1.487	0.378	15.535	37.010
Fe <sub>2</sub> O <sub>3</sub> <sup>tot</sup>	0.104	0.109	---	0.033	0.027	0.164	0.452
TiO <sub>2</sub>	0.369	0.192	---	0.040	0.057	0.505	0.590
P <sub>2</sub> O <sub>5</sub>	0.086	0.046	---	0.011	0.000	0.023	0.103
Na <sub>2</sub> O	0.019	0.000	---	0.000	0.000	0.063	0.053
MgO	0.080	0.000	---	0.000	0.000	0.000	0.000
K <sub>2</sub> O	0.013	0.000	---	0.000	0.000	0.024	0.023
CaO	0.195	0.080	---	0.665	0.000	0.065	0.130
MnO	0.006	0.000	---	0.000	0.000	0.000	0.000
Cr <sub>2</sub> O <sub>3</sub>	0.010	0.000	---	0.000	0.000	0.000	0.000
SO <sub>3</sub>	0.064	0.052	---	0.062	0.035	0.045	0.064
ZrO <sub>2</sub>	0.028	0.019	---	0.032	0.028	0.151	0.030
L.O.I	1.600	4.609	---	0.807	1.307	3.903	14.500

TABLE 8

CHEMICAL ANALYSIS RESULT OF SILICA SAND HEAD SAMPLE AND ITS SIZE FRACTIONS

Size (µm)	HS3	Size fraction (µm)				
		+2000	-2000+800	-800+500	-500 +180	-180
SiO <sub>2</sub>	99.454	---	99.774	99.598	99.448	97.573
Al <sub>2</sub> O <sub>3</sub>	0.312	---	0.108	0.062	0.270	0.351
Fe <sub>2</sub> O <sub>3</sub> <sup>tot</sup>	0.017	---	0.028	0.017	0.032	0.054
TiO <sub>2</sub>	0.027	---	0.020	0.000	0.034	0.219
P <sub>2</sub> O <sub>5</sub>	0.036	---	0.005	0.000	0.000	0.007
Na <sub>2</sub> O	0.019	---	0.016	0.000	0.032	0.030
MgO	0.008	---	0.000	0.000	0.000	0.000
K <sub>2</sub> O	0.003	---	0.000	0.000	0.000	0.000
CaO	0.048	---	0.022	0.010	0.022	0.033
MnO	0.000	---	0.000	0.000	0.000	0.000
Cr <sub>2</sub> O <sub>3</sub>	0.000	---	0.000	0.000	0.000	0.000
SO <sub>3</sub>	0.068	---	0.010	0.301	0.141	0.035
ZrO <sub>2</sub>	0.005	---	0.013	0.012	0.021	0.184
L.O.I	0.000	---	0.000	0.000	0.000	0.000

##### 4.5.3 Compatibility of chemical composition with the industrial specifications

As dug, Wadi Qena Formation sandstones have not a suitable chemistry to be used directly for glass production or other industrial applications. They need to be subjected to beneficiation processes to increase the SiO<sub>2</sub> content of the raw sands and to reduce iron and titanium compounds, their contents of contaminants (clay and heavy minerals) to achieve the desired "cleaned particles" and improve their quality in order to meet the specifications required for the production of glass and other industrial applications.

However the chemical analysis of liberated size fractions using attrition scrubbing technique showed that; the size fractions of 600 to 90µm has a chemical composition suitable for grade 'F' glass making sand according to specifications of British standards (B.S.) [10] or grade '2' glass making sand according to Indian standards [11] "Table 7". In addition, it meets the specifications of many industries, such as Metallurgical silicon, chemical based silicon, ceramic industry and abrasives.



The -45 $\mu$ m size fraction chemically contains 46.959% of SiO<sub>2</sub> and 37.01% of Al<sub>2</sub>O<sub>3</sub>; the composition compatible with the required specifications for kaolin grade '1' according to Indian standards [16] after grinding to the required grain size, as it composed essentially of kaolin clay mineral as shown by SEM and petrography studies.

The chemical composition of the particle size ranges from 0.6 to 2mm showed that SiO<sub>2</sub> is 96.855 %, Fe<sub>2</sub>O<sub>3</sub> is 0.033%, and TiO<sub>2</sub> is 0.040%; the chemical composition suitable to foundry sand Grades 'B' (850/425) according to Indian specifications [17]. It also can be used as glassmaking sand grade 'G' according to B.S. after crushing and sieving to obtain the required size gradation. In addition, it meets the specifications of industries, such as abrasives and silica bricks.

Generally, the chemical analysis of the whole rock and size fractions of the silica sand sample (HS3) from Somr El-Qaa Formation showed relatively high silica content and low contents in the other oxides. This indicates a good potential source rock to start with to produce high silica sand.

The chemical composition of -500 to +180 $\mu$ m size fraction showed that SiO<sub>2</sub> is 98.168%, Fe<sub>2</sub>O<sub>3</sub> is 0.027%, and TiO<sub>2</sub> is 0.028%. It is suitable for grade 'E' glassmaking sand according to specifications of British standards (B.S.) or special grade glassmaking sand according to Indian standards. It is also meets the specifications of many industries, such as chemical based silicon, ceramic industry and abrasives.

The -800 to +500 $\mu$ m size fraction represents about 17.30 wt% of the studied deposit. The chemical composition "Table 8" showed that it contains 99.598% of SiO<sub>2</sub>, 0.017% of Fe<sub>2</sub>O<sub>3</sub>, and 0.062% of Al<sub>2</sub>O<sub>3</sub>. The chemical composition suitable to foundry sand Grades 'A' (850/425), according to Indian specifications. In addition, it meets the specifications of many industries, such as Metallurgic silicon, chemical based silicon, ceramic industry and abrasives. It also can be used as glassmaking sand grade 'B' or 'C' according to B.S. after crushing and sieving to obtain the required size gradation..

The -0.80 to +2mm size fraction represents about 5.54 wt.% of the studied deposit. The chemical composition showed that SiO<sub>2</sub> is 99.774%, Fe<sub>2</sub>O<sub>3</sub> is 0.028%, and TiO<sub>2</sub> is 0.108%; the chemical composition suitable for foundry sand Grades 'B' (850/425), according to Indian specifications. It also can be used as glassmaking sand grade 'A' according to B.S. after crushing and sieving to obtain the required size gradation, and can be also used as hydraulic fracturing sand with some limitation in the sphericity parameter, which can be overcome by coating with resin. In addition, it meets the specifications of many industries, such as Metallurgic silicon, chemical based silicon, ceramic industry and abrasives.

The +2mm size fraction represent only about 0.2, it is likely to have high silica content. This size fraction can be blended and mixed with other size fractions to meet the required size gradation of CEN sand, filter media sand and silica sand bricks, or it can be collected separately to use in non-industrial applications.

The - 0.180 mm size fraction represents only about 1.18 wt.% of the studied deposit. The chemical composition showed that SiO<sub>2</sub> is 97.573%, Fe<sub>2</sub>O<sub>3</sub> is 0.054%, and TiO<sub>2</sub> is

0.351%, the chemical composition suitable for grade 'F' glassmaking sand according to specifications of British standards (B.S.), with limitations in grain size gradation and Loss on ignition. It also can be used as raw material for produce silica flour. In addition, it meets the specifications of many industries, such as chemical based silicon, ceramic industry, refractory, silica bricks, and abrasives.

## 5 CONCLUSIONS

A detailed laboratory study was conducted on head samples from Wadi Qena and Somr El-Qaa Formations sandstone to evaluate and characterize the white sands, that including the study of their physical, mineralogical, and geochemical properties as raw material.

The grain size analysis results showed that the HS1 and HS2 samples are well graded, while HS3 sample was poorly graded. The median size (d50) of the HS1, HS2, and HS3 samples is 220 $\mu$ m, 222 $\mu$ m, and 365 $\mu$ m, respectively; which indicate that the studied sandstone samples are mainly medium-grained size.

The morphological study results of the HS1, HS2, and HS3 samples showed that; the average circularity and angularity of HS1 and HS2 head samples size fractions ranged from 0.72 to about 0.81 and from about 0.24 to 0.43, respectively. HS3 head samples size fractions ranged from about 0.70 to about 0.80 and from about 0.38 to 0.54, respectively.

The identification XRD study of HS1 and HS2 samples indicated that the quartz and kaolinite clay mineral were found as major constituents, while the mineralogical investigation of HS3 sample indicated that the one and only major mineral constituent was quartz. The total weight percentage of the heavy minerals in the studied fractions was found to be 0.036% for the silica sand sample and 0.05 to 0.06% for the kaolinitic sand sample, the amount of the heavy minerals found in both samples was very little.

The Sandstones of Wadi Qena dominated by quartz wackes, while the Sandstone of Somr El-Qaa Formation dominated by quartz arenites. The detrital mode of both deposits is characterized mainly by the removal of all mineral except quartz and refractory accessory grains.

The results of the chemical analysis for the whole kaolinitic sandstone samples revealed that the proportions of SiO<sub>2</sub> range from 87.56 to 95.11%; of Al<sub>2</sub>O<sub>3</sub> from 3.39 to 9.83%; of Fe<sub>2</sub>O<sub>3</sub> from 0.01 to 0.09%; and of TiO<sub>2</sub> from 0.09 to 0.36%. Silica sand head sample (HS3) revealed that the proportions of SiO<sub>2</sub> range from 87.56 to 95.11%; of Al<sub>2</sub>O<sub>3</sub> from 3.39 to 9.83%; of Fe<sub>2</sub>O<sub>3</sub> from 0.01 to 0.09%; and of TiO<sub>2</sub> from 0.09 to 0.36%. This indicates a good potential source rock to start with to produce high silica sand.

Generally the characterization revealed that the studied deposits are suitable for the specifications of many industries such as glassmaking, abrasive, hydraulic fracturing, water filtration, building products, chemicals and Semiconductors; as dug or with some essential beneficiation processes such as sizing and classification to produce the required size gradation, attrition scrubbing to iron oxide-clay coating removal and flotation to heavy mineral elimination.

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