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Assessment of Oligocene Sandstone for Glass Industry: Case study of Halkani Sandstone Member, Sona Pass area, Karachi Pakistan

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Abstract: Present study is carried out for the assessment of Halkani sandstone cropping out in the southwestern part of Karachi city. For this purpose, 20 rock samples were collected along Sona Pass area for geochemical and petrographic examination. Petrographic data revealed that the sand is mainly composed of quartz grains followed by feldspar and mica minerals in traces. Particle morphology revealed that mostly the sand is well sorted, sub rounded to angular where some grains show microfractures. Grain size analysis discovered that Halkani sand has 0.149 mm (100 mesh) size as modal class followed by 80 and 200 mesh. Chemical analysis revealed that silica content is about 86.2%. The mean concentration of Fe_2O_3 is 2.16% which is double the standard guidelines (< 1%). Conversely, mean concentration of Al_2O_3 is 2.96% which is within allowed limit of US standard (< 4%). Other major oxides including CaO (mean: 0.9%), MgO (0.44%), Na_2O (0.3%) and K_2O (0.32%) are within corresponding desired limits. Other trace elements (Cr_2O_3, ZnO, CoO, TiO_2, CuO, BaO) varied between 0.03-0.2%. the mean wt% of B_2O_3 is 15.33% which is slightly above fiber glass requirement (10%). This sand is devoid of NiO, MnO and PbO (below detection level). These results indicate that Halkani sandstone is generally suitable for various types of glass. Further beneficiation can improve it for high grade glass manufacturing.

Keywords: Sandstone, silica sand potential, glass industry, Karachi.

Introduction

Silica has been started to use since ancient time. Initially it was used in glass making. Silica sand is one of the most common and second most abundant mineral occurring on earth crust (Edem et al, 2014) which crystallizes in the last stage of Bowen's reaction series. It occurs in all kinds of rock i.e. igneous, metamorphic and sedimentary (Ketner 1973; Bourne 1994). Silica is an important part of the rock cycle which occurs in the last stage of rock weathering (Shaffer 2006) and exist in nine different crystalline forms or polymorphs the most common forms are tridymite and cristobalite. It also occurs in cryptocrystalline form. Chalcedony and semi-precious stone such as agate, onyx and carnelian are the fibrous forms of silica. Granular varieties include jasper and flint (Malu et al, 2015) while anhydrous forms include diatomite and opal (Press 2001; Tsoar 2004; Wilkinson 2005).

Sandstone, quartzite and loosely cemented or unconsolidated sand deposits are the main source of silica sand (Press 2001; Tsoar 2004; Wilkinson 2005). The deposits of silica sand are extensive throughout the world, mostly in non-tropical regions which are used for different purposes (Freestone 2005; Heck et al, 2002). It is utilized in various applications due to the fact that it is hard, chemically inert, resistant to heat and weathering and has a high melting point which is due to the strength of the bonds between atoms. Industrial sand and gravel, often termed "silica," "silica sand" and "quartz sand" includes high SiO_2 content sands and gravels (Bolen 1996). The uses of silica sand depend on its mineralogy, chemistry and physical properties. It is mainly used for making glass and glass fiber, silicon carbide, sodium silicate, Portland cement, silicon alloys and metals, filter media in water treatment, sand paper and also for foundry sand, hydraulic fracturing, sand blasting, paint and a host of other applications (Sundararajan et al, 2009). Natural glasses formed on Earth during rapid cooling of melts ranging in composition from basalt to rhyolite such as obsidian (Hossain 2013). The quality of commercial glass produced is highly dependent on mineral raw material used in the process (Hamidullah et al, 1996). Good quality silica sand reserves are situated in UK, Germany, Belgium, France, Brazil etc. In Pakistan, large deposits of silica sands are found in the Eocene and Oligocene starta near Thano Bula Khan in Dadu district (Malkani et al, 2016). Silica Sands is also found mostly in the sandstone of Toi and Kingri

Formations and Vihowa group in Sulaiman fold belt. In Toi and Kingri formations, it occurs in Duki, Chamalang, Alu Khan Kach (Gharwandi), Kingri and Shirani area, while from the Vihowa Group it is reported in the Zinda Pir, Taunsa and Dera Bugti area (Malkani et al, 2016). Good quality silica sand is reported in rock deposits in Munda Kuchha area; district Manshera, Punjab province (Hamidullah et al, 1996; Alauddin et al, 1992). Beside all these sand deposits, Karachi district is also blessed with clastic sediments of Tertiary age where Halkani sandstone of Oligocene are widely exposed with significant thickness of about 20 meters. This rock unit is a potential source of Silica Sand for glass. However, no work has been carried out so far, the economic potential of the Halkani sandstone. Therefore, present study is aimed to assessing the Halkani sandstone, for its glass potential to be used commercially.

Study area

Study area is located on the South west of Karachi city near Sona Pass area, Mubarak Village. It is located on the western flank of Cape Monze anticline (Fig. 1) at the southern end of the Kirthar fold belt, west of Karachi. Coordinates of study area lies between $24^{0} 53^{/} 30.374^{//}$ to $24^{0}54^{/} 34.5271^{//}$N and $66^{0} 45^{/} 32.9801^{//}$ to $66^{0} 46^{/} 14.3248^{//}$E.

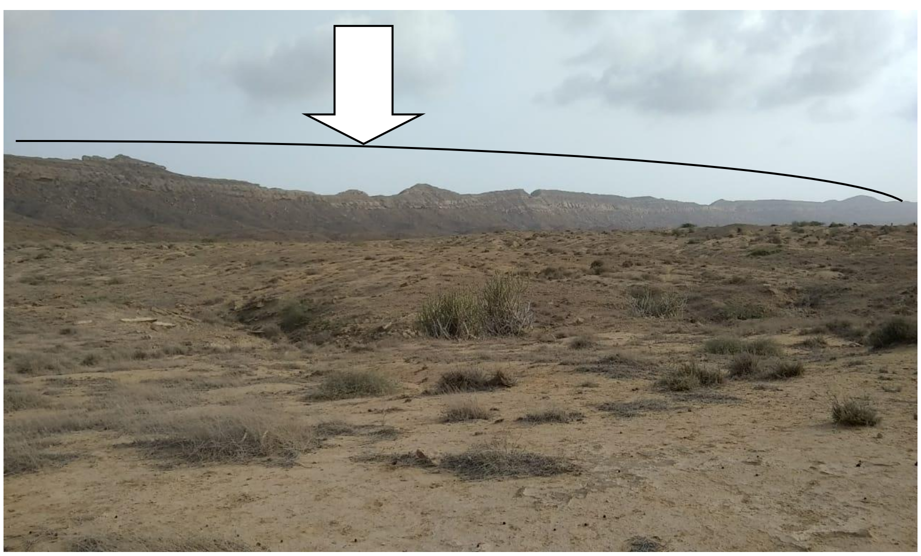


Figure 1 Western flank (shown by arrow) of Cape Monze anticline.

Hub river is present on the northwest while Sona Pass fault occurs on northeast. The study area is accessible from Kemari town and it is located about 6-7 km from Hawks Bay. Nari and Gaj Formations of Oligocene and Miocene age respectively are exposed in the study area which is mainly clastic in nature. Halkani sandstone is the second member of Nari Formation of Oligocene age. The basal part of rock cropping out is sandstone with thinly to thickly bedded clay followed by siltstone. This sand is hard medium to coarse grained, gritty, medium bedded and friable in nature.

Material and Methods

Sampling

Field work was carried out to collect sandstone samples (n=20) from Halkani member of Nari Formation cropping out along Sona pass fault, Karachi (Fig. 2). About 2 kg of sand was collected from each sample location at an interval of about 25 meters from each other. The samples were properly numbered and packed into sample bags for laboratory analysis. The field coordinates of collected samples were noted by using Global Positioning System (GPS). Mineral composition and cementing material were tested in situ by visual examination method using hand lens and HCl (10%).

Figure 2 Map showing the samples location at Sona pass area, Karachi.

Sample Analysis

Grain size analysis

About 500 gm each of the collected samples was oven dried at 105^{0}C for 2 hours to remove moisture content. The dried samples were analyzed for grain size distribution by using dry sieving technique as prescribed by Folk (1980). The sand samples were shaken thoroughly for 20 minutes by using US standard set of sieves having mesh# 20, 30, 40, 60, 80, 100, 120 and 200. The retained fractions were weighed on Triple Beam Balance and calculated. The whole process was carried out in air tight environment.

SEM-EDS analysis

Scanning Electron Microscope coupled with Energy Dispersive Spectrum analysis was carried out to investigate the particle morphology and major oxides of representative sand samples. For SEM-EDS analysis, the rock samples were disintegrated in laboratory by mortar and pestle. About 10g of each sample was separated from the blend. Eight representative samples were selected for analysis based on color and texture. The analysis was carried out by using SEM fitted with EDS (Model: JEOL- JSM-6380A). The grains were mounted on SEM brass stub. The mounted grains were coated with gold in 10N sputtering device JF C-1500. Typical micro-photographs were taken with different magnifications (x40 – x6,000), along with EDS at 15.00 kV by using the liquid nitrogen for cooling effect on each of the representative sample. The results were expressed as percent oxide concentration.

Petrography

For detailed petrographic analysis sediments were examined under binocular microscope. Typical micrographs were taken to visually inspect the mineral constituents and grain morphology (size, shape and iron coating on mineral grains).

Results and Discussion

Grain size distribution: The grain size distribution results of Halkani sandstone samples (n=18) have been summarized in Table 1. Data revealed that none of the samples retained on mesh 20 (0.84mm) which is indicating that Halkani sandstone is devoid of any coarse fraction so it can be used for glass manufacturing because larger grains melt slower than smaller grain and may remain non-melted causing stones in the glass final product (GWP consultant 2010). Minimum fraction retained on mesh 30 was about 0.02% and maximum of 1.8%. Similarly, on mesh 40, minimum retained fraction was about 0.18% and maximum of 6.82%.

Mean retained fraction on mesh 40 is ten times higher than the mean fraction (0.32%) retained on mesh 30 (Table 1). On the other hand, mean fraction retained on mesh 60 was about 10.55% with minimum and maximum of 3.62% and 13.66% respectively. Except sample 20, all the collected samples have shown more than 9% retention on mesh 60 (Table 1). As a whole, weight % retained on both mesh 30 and 40 is less than 10% which is suggesting that the Halkani sandstone is deficient in medium grain size. On the other hand, mesh 80 shows about 19.55% as mean retention of sediments which is double the retained weight on mesh 60 (Table 1). Likewise, minimum and maximum wt.% retained on mesh 80 is 8.56% and 34.56%. Particle size is very significant for glass making as larger grains do not mixed properly with other grain while too fine grain creates air bubble in the glass final product (Robert 2002; Corning Glass Works 1967; Crockford 1949). Hence, grain size distribution should fall within the 40-100 screen mesh size (Edems et al, 2014).

The large variation in the mean size of all fractions reflect the fluctuation in energy condition during sediment deposition (Baiyegunhi et al, 2017). Sediments retained on mesh 100 were about 42.8% of total mass which is four times and double the wt.% retained on mesh 60 and 80 respectively (Table 1). The specifications of glass sand usually require the largest amount of material to be between 30 and 140 mesh (Carpenter et al, 2000). Grain size analysis shows that mesh 100 contain more than 40 wt% portion of sand and it is more beneficial to increase production quality. It is indicating that Halkani sandstone comprises of fine sediments where mesh 100 shows its Modal class. The predominance of fine sediments and absence of coarse one indicates the prevalence of moderate to low energy conditions during deposition (Boggs 2009). Likewise, none of the sample showed sediments retention on mesh #120 which is suggesting that Halkani sandstone is not only devoid of coarse fraction but very fine sediments as well. Fraction retained on mesh 200 is 50% of the fraction retained on mesh 100 with minimum and maximum of 11.96% and 34% respectively (Table 1). Standard deviation values for the fraction retained on mesh 80, 100 and 200 revealed that significantly variable size population is present in Halkani sandstone (Table 2) which is the function of fluctuation in energy of depositional environment. In general, Halkani sandstone is fine grained which exhibits unimodal class.

Particle Morphology: The collected sand samples show distinct sets of surface features on microphotographs taken by using Scanning Electron Microscope (SEM). SEM images of representative collected samples revealed that the sand is well sorted and shape of the sand grains is sub-rounded to angular (Fig. 5). Angularity of the studied grains suggest less transportation (Hussain et al, 2006). Angular grains are beneficial for melting as these melts faster than rounded grain of same size, it is due to the fact that angular grain exposes more surface to heat than rounded grain (Lamar 1928). On microphotographs, some pits and microfractures have been observed (Fig. 6a-6b) which are formed by mechanical or chemical weathering (Zhao et al, 2015). According to Zhao et al, (2015) fracture pattern is strongly influenced by initial microstructures that caused the structural weakness. Presence of step like fractures and cleaved plane (Fig. 7a-7b) suggests fractures in feldspar grains because it has two cleavage sets that intersects at about 90^0 (Zhao et al, 2015). This type of microfractures are created by weathering (Lee & Coop 1995). Moreover, some irregular microfractures are formed in response to tectonic stress. on sand grain are due to the proximity with Sona Pass fault. On the other hand, SEM analysis shows the occurrence of conchoidal fractures (Fig. 8), which are free from structural weakness. These fractures are generated in the quartz because it is lacks cleavage (Zhao et al, 2015). Hence, presence of conchoidal fractures on studied sediments revealed that the sand grains are mainly composed of quartz mineral. Fractured grain is good for glass making as week zone present in fractured sediments initiate melting. It is obvious from SEM images that most of the sand grains have freshly cleaved grain along with equant habit (Fig. 9a-9b). Moreover, it is further evident by SEM images that Halkani sand is subjected to weathering as it is seen by weathered surfaces on sand grain (Fig. 10a-10b).

Table 1 Grain size analysis results of Halkani Sandstone, Karachi.

Sample	Retained %									Total %	Mean
	20	30	40	60	80	100	120	200	pan		
02	-	0.04	3.82	13.02	17.22	42.22	-	20.62	2.22	99.16	14.16
03	-	0.06	1.7	9	13.18	56.02	-	16.06	3.12	99.14	14.25
04	-	0.02	2.08	10.2	9.6	53.6	-	19.4	4.9	99.8	14.25
05	-	0.06	2.96	11.06	18.4	44.68	-	19.18	3.44	99.80	14.20
06	-	0.52	5.96	16	27.98	35.44	-	11.96	2.58	99.64	14.28
07	-	0.06	2.1	11.4	30.34	37.48	-	14.4	4.2	99.98	14.21
08	-	0.08	1.5	10.38	21.74	46.78	-	15.28	3.76	99.52	14.27
09	-	0.56	4.74	9.56	12.52	47.7	-	20.82	4	99.9	14.26
10	-	0.08	2.46	9.86	14	40.46	-	27.32	5.64	99.82	14.25
11	-	0.7	4.42	9.1	20.94	47.02	-	15.03	2.6	99.81	14.24
12	-	0.68	6.38	13.66	20.54	34.72	-	20.12	3.6	99.7	14.26
13	-	0.04	1.52	10.24	23.9	43.9	-	16.06	4.2	99.84	16.62
14	-	-	2.86	10.26	17.6	49	-	17.22	2.82	99.76	14.26
15	-	0.08	3.64	10.84	17.84	39.32	-	21.68	6.44	99.84	16.65
16	-	-	2.86	10.04	18	48	-	18.22	2.82	99.96	14.25
17	-	1.8	6.82	10.86	8.56	31.86	-	34	5.88	99.78	14.19
19	-	0.08	3.04	11.04	34.56	31.24	-	14.28	5.1	99.34	16.51
20	-	-	0.18	3.62	33.18	41.08	-	17.74	3.28	99.08	**14.17**
Mean	**-**	**0.32**	**3.28**	**10.55**	**19.55**	**42.80**	**-**	**18.85**	**3.91**	**99.72**	**32.50**
Cumulative%	**-**	**0.32**	**3.6**	**14.15**	**33.7**	**76.5**	**-**	**95.35**	**3.91**	**99.26**	**-**
ST. DEV	**-**	0.481	1.808	2.443	7.585	7.035	**-**	5.166	1.235	0.288	0.906

Table 2 Statistical descriptive of Halkani sandstone (n=18)

Mesh #	Minimum	Maximum	Mean	Standard Deviation
20	-	-	-	-
30	0.02	1.8	0.32	0.4812
40	0.18	6.82	3.28	1.808
60	3.62	13.66	10.55	2.443
80	8.56	34.56	19.55	7.585
100	31.24	56.02	42.80	7.035
120	-	-	-	-
200	14.28	27.32	18.85	5.166
pan	2.22	6.44	3.91	1.235

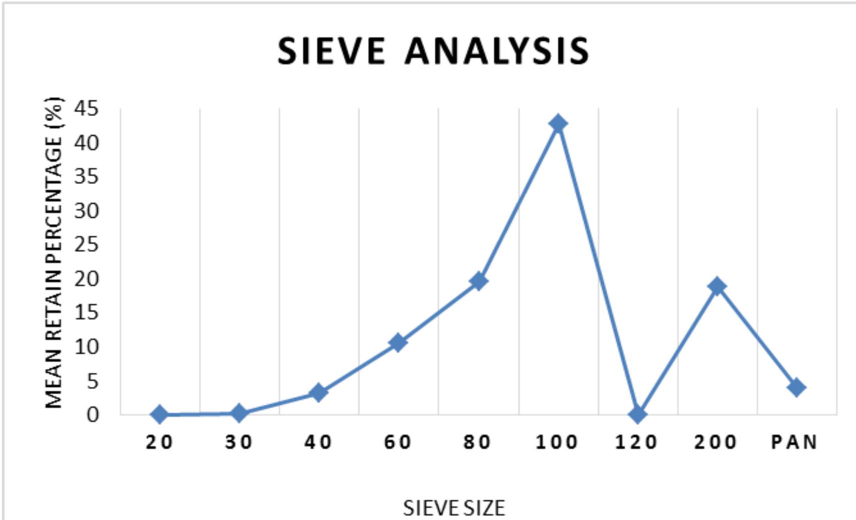
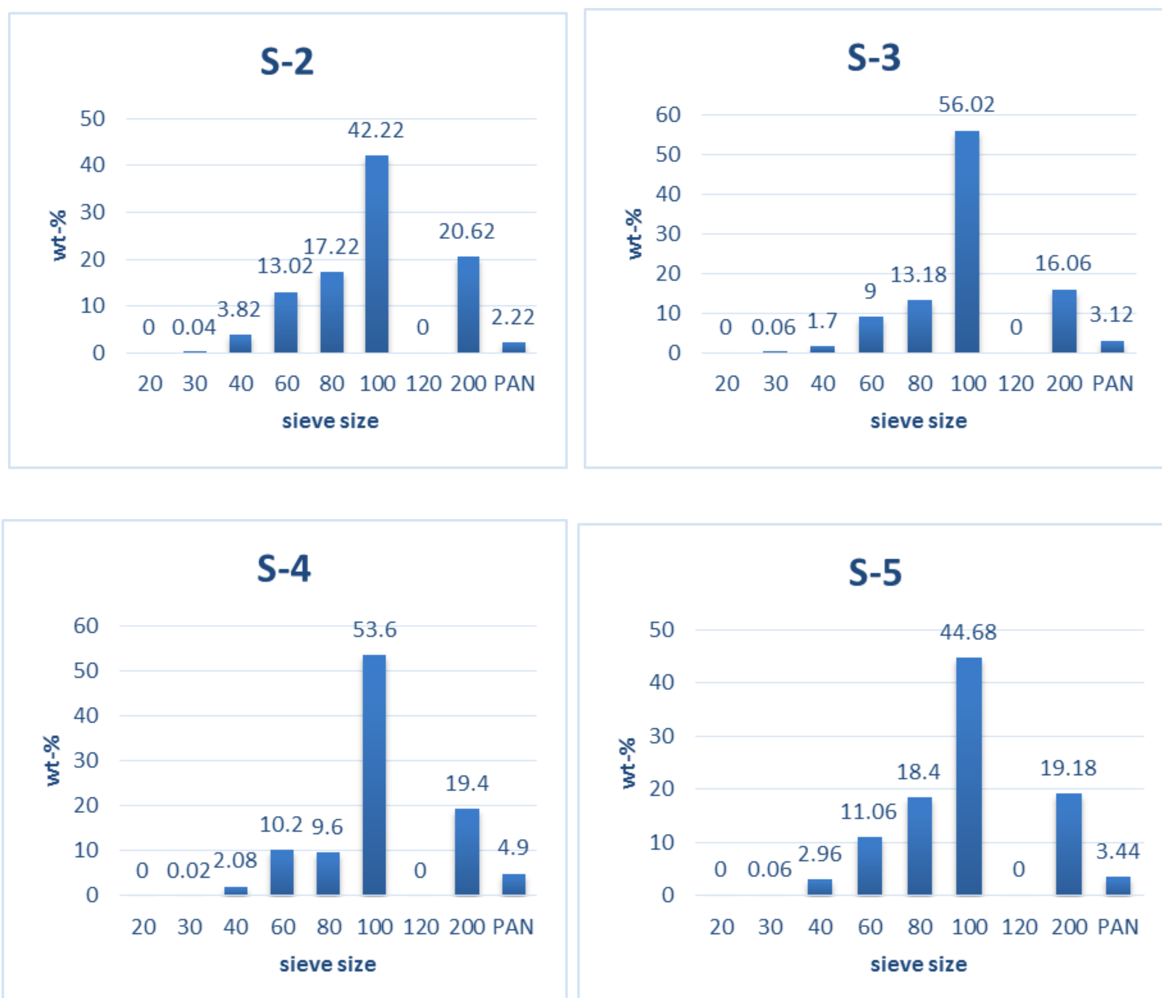
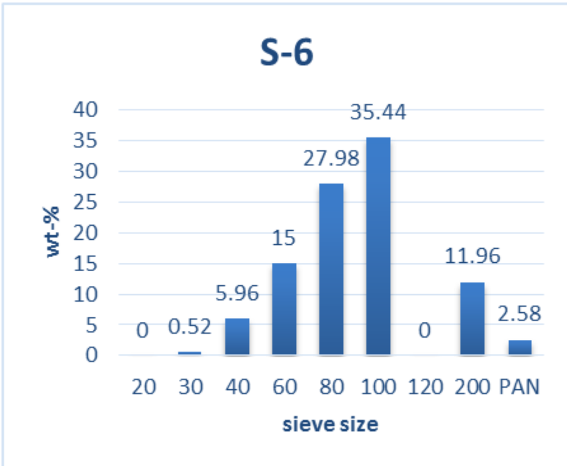
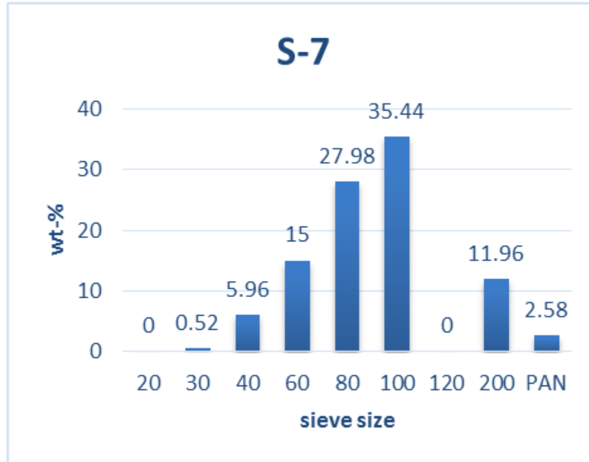
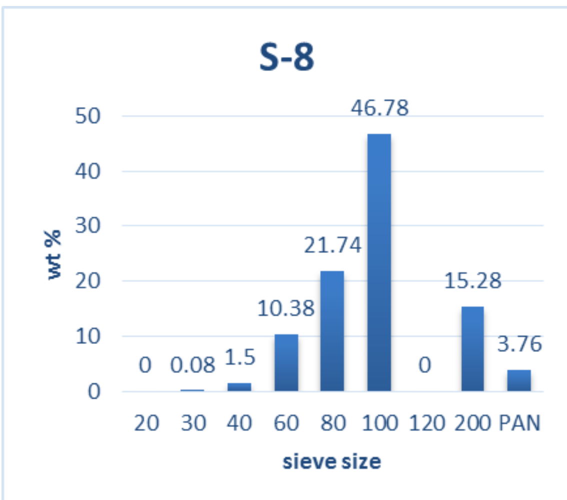


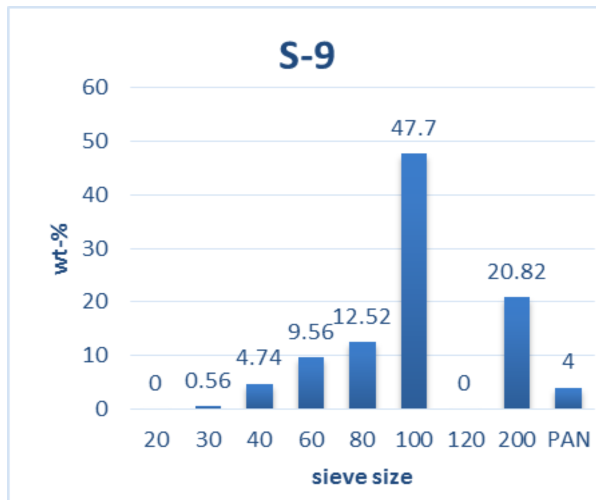
Figure 3 Showing the mean grain size distribution of Halkani sandstone.

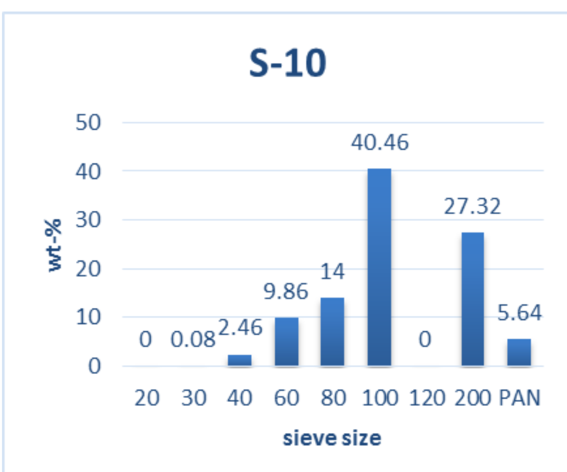


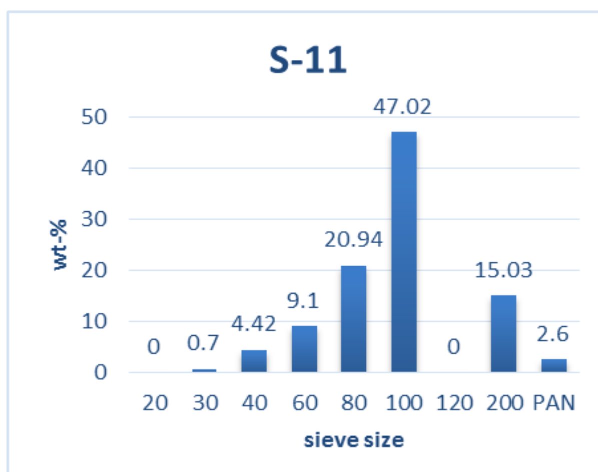

S-6
wt-%
0 0.52 5.96 15 27.98 35.44 0 11.96 2.58
20 30 40 60 80 100 120 200 PAN
sieve size


S-7
wt-%
0 0.52 5.96 15 27.98 35.44 0 11.96 2.58
20 30 40 60 80 100 120 200 PAN
sieve size


S-8
wt-%
0 0.08 1.5 10.38 21.74 46.78 0 15.28 3.76
20 30 40 60 80 100 120 200 PAN
sieve size


S-9
wt-%
0 0.56 4.74 9.56 12.52 47.7 0 20.82 4
20 30 40 60 80 100 120 200 PAN
sieve size


S-10
wt-%
0 0.08 2.46 9.86 14 40.46 0 27.32 5.64
20 30 40 60 80 100 120 200 PAN
sieve size


S-11
wt-%
0 0.7 4.42 9.1 20.94 47.02 0 15.03 2.6
20 30 40 60 80 100 120 200 PAN
sieve size

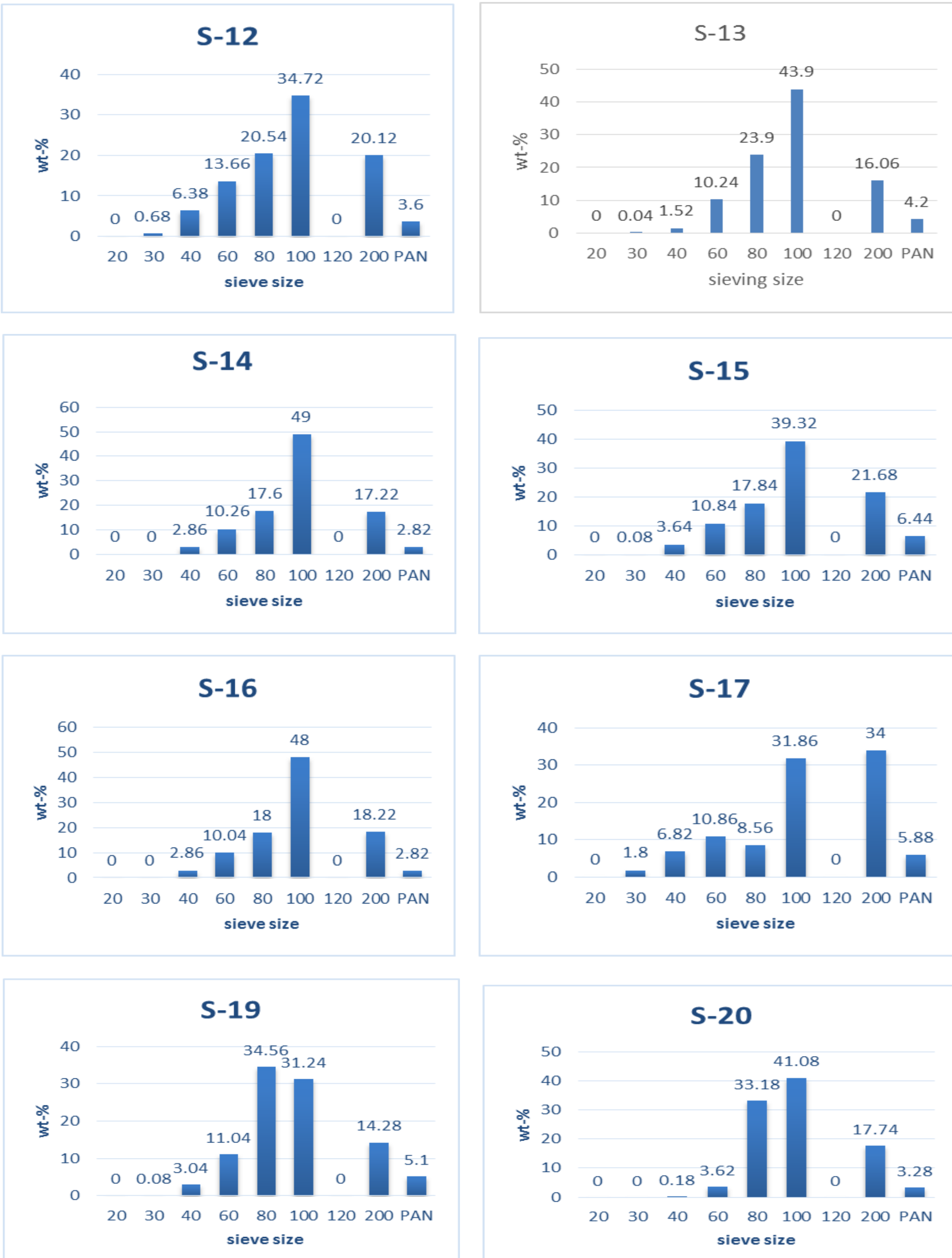


Figure 4 Graphical representation of grain size distribution.

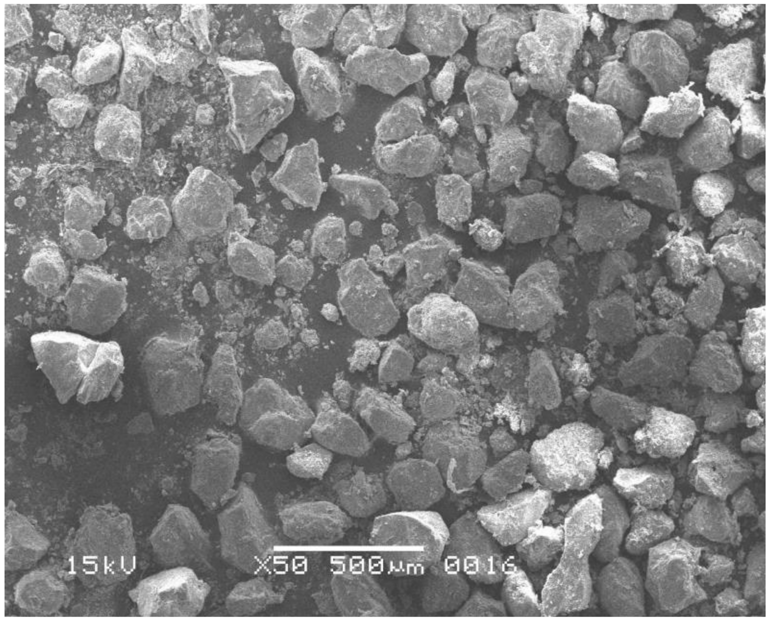


Figure 5 SEM image showing well sorted and angular sand grain.

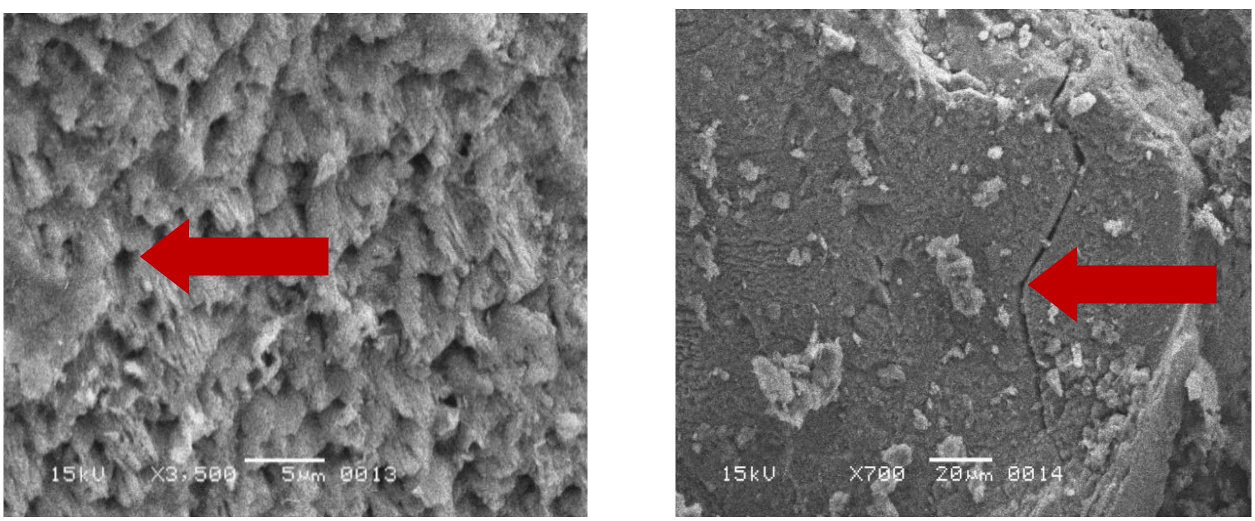


Figure 6 SEM image showing (a) pits on sand grains (b) microfracture on feldspar grain.

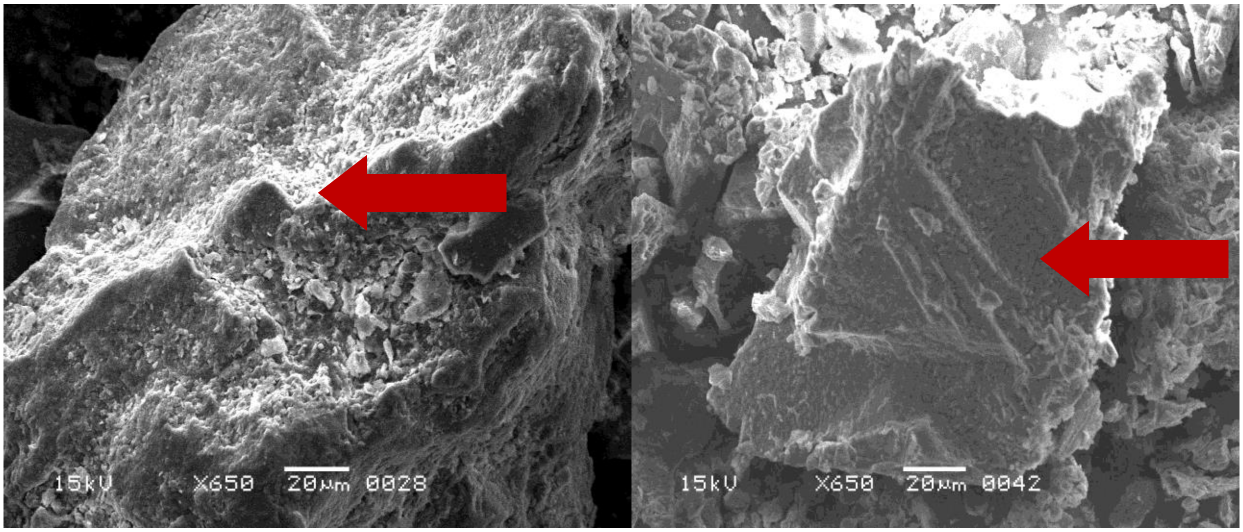


Figure 7 SEM image of represented sample showing (a) step like fracture (b) cleaved plane on feldspar grain.

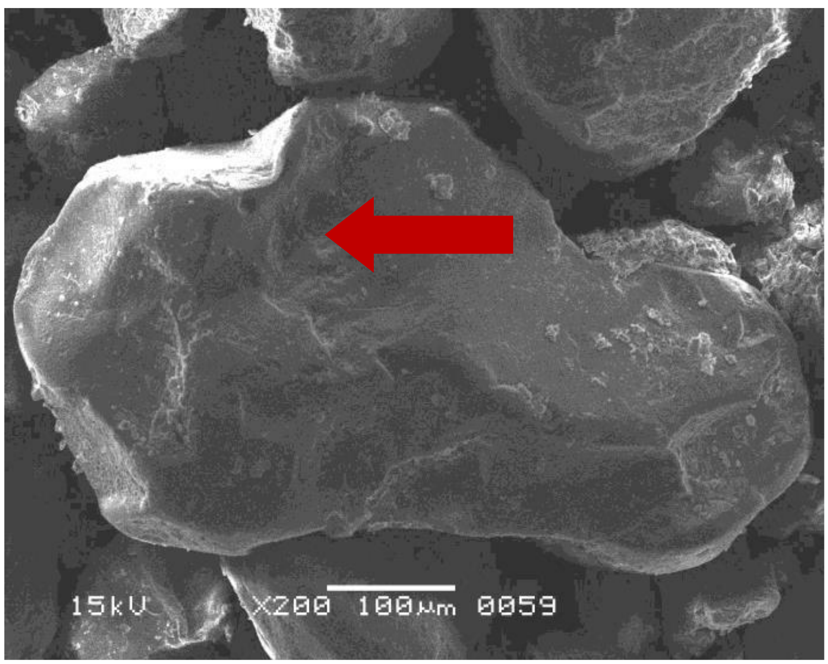


Figure 8 Conchoidal fractures obvious on quartz grains.

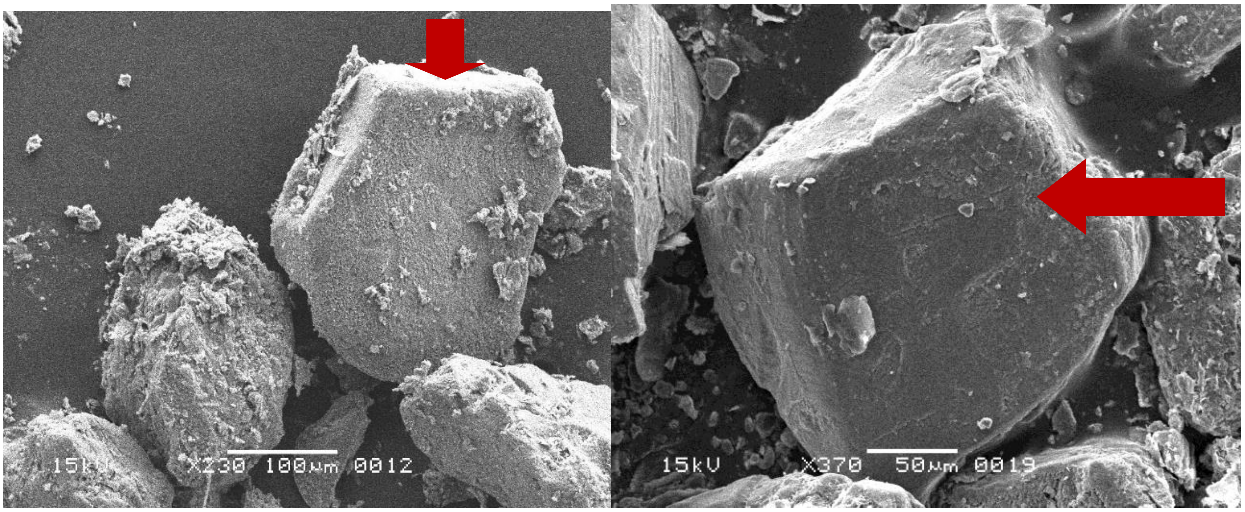


Figure 9 (a-b) SEM image showing freshly cleaved grain with equant habit.

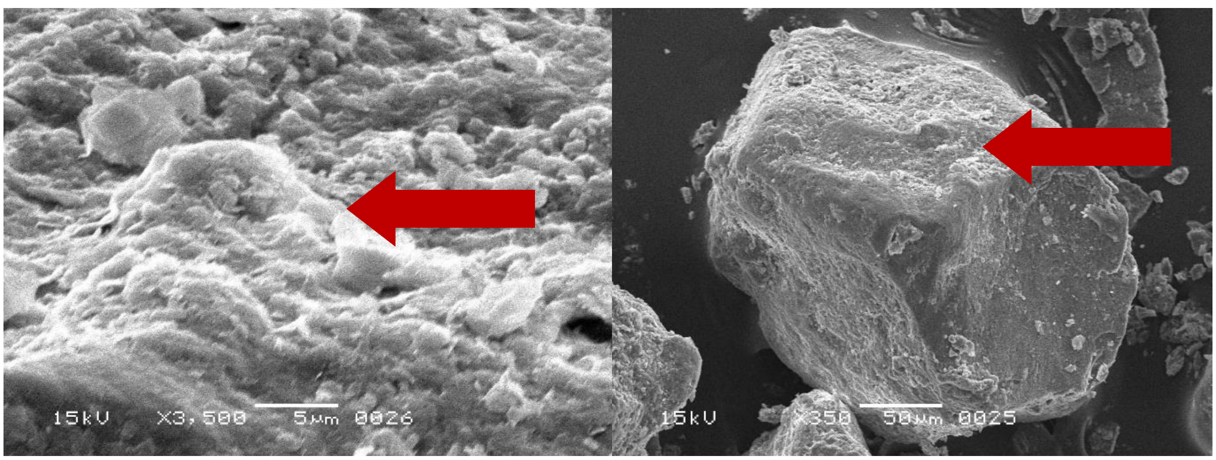


Figure 10 SEM image showing (a) completely weathered surface (b) partly weathered surface of sand grain.

Major Elements Geochemistry

Major element geochemistry of the rock give clue about weathering condition and provenance (Ben et al, 2016). The mean concentration of corresponding metal oxide (wt%) of representative samples have been listed in Table 1. Data reveal that the mean concentration of SiO_2 is about 86.2% is dominant over the other oxides such as Al_2O_3, TiO_2, CuO, Cr_2O_3, CoO, CaO, MgO, Na_2O, K_2O, ZnO, B_2O_3. The high SiO_2 content in all the samples indicate occurrence of high silica mineral. Silica sand generally consist of quartz with high SiO_2 contents (Sosman 1954; Bajah 1986; Siever 1988). It is advocated by the fact that the high amount of quartz is reported in binocular microscope studies (Fig. 11).

Hence, the quality of Halkani sand is good for glass making. However, some impurities have been reported to exceed corresponding permissible guidelines. The major impurity such as Fe_2O_3 is found to be 2.16% which is about 400 times higher than the prescribed value (>1%) for high quality glass (Hossain et al., 2013). The specification of iron oxide (Fe_2O_3) in silica sand reported for clear container glass, amber glass, chemical glass-ware, high-grade domestic and decorative glass-ware are 0.06%, 0.25%, 0.02%, 0.013% respectively (Faruqui 1967). Despite of relatively high amount iron oxide in Halkani sandstone can be beneficiate through processes such as chemical and biological method (Bahaz et al, 1996; Strasser et al, 1993; Faruqui et al, 1970). Furthermore, silica sand samples can also be upgraded by reducing the iron content using electromagnetic separation techniques (Bulychev et al, 1994). Besides, the iron oxide can be used as coloring agent in colored glass (Brems et al, 2012; Platias et al, 2014; Uchino et al, 2000).

According to Platias et al, (2014) heavy metals such as TiO_2 and Cr_2O_3 also gives color to the glass. TiO_2 is reported only in three sample in the range of 0.01-0.9 % with mean of 0.09 likewise the Cr_2O_3 is below detection limit except 2 samples Table 3. According to Mclaws (1971) companies' specification 1969 suitable maximum concentration of TiO_2 and Cr_2O_3 is (0.05 & 0.0003 %). The other oxides such as CoO is reported only in sample 22a (0.607%) while the other 4 samples are free from CoO (Table 3). According to Mclaws (1971), CuO and CoO should not exceed 0.0001%. All these heavy metals such as TiO_2, Cr_2O_3, CoO and CuO can be removed by heavy liquid separation technique by sodium polytungstate method. (Hajjaji et al, 2009). Concentration range of CaO is 0.01-2.21% whereas the minimum and maximum concentration of Al_2O_3, MgO ranges from 1.89-5.12 and 0.13-0.95 % respectively.

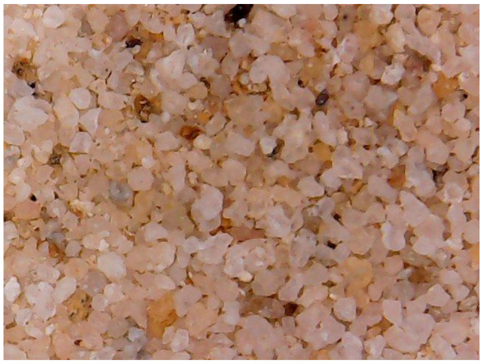
While glass making aluminum oxide magnesium oxide and calcium oxide, are added to give the glass stability and chemical durability (Mclaws 1971) When the amount of these three oxides exceeds their corresponding percentages the melting properties of the glass are affected (Platias et al, 2014). The content of Na_2O in analyzed samples ranges between

0.05-0.69%. Sodium oxide is added in the glass as fluxing agent (Silvestri et al, 2006; Smedley et al, 1998). Where glass making sand generally contain less Na_2O hence the low amount of Na_2O in Halkani sandstone make it feasible for glass making. Other oxides (K_2O, ZnO and BaO) have been reported as <0.6% in collected samples. Likewise, the mean concentration of B_2O_3 is 10.43% according to which Halkani sandstone fulfills the specification for glass fiber which requires about 10% B_2O_3 and vycor high temperature scientific glassware needs 2.9% (Table 5).

According to Highly et al, (2007) about 70 – 74% SiO_2 is required for soda lime silica glass. The mean silica content is found to be 86.2%. Hence, Halkani sandstone qualifies for making soda lime silica glass. General specification in terms of chemical composition for glass sand is given in Table 4 which shows that green glass, amber glass, insulating fiber, clear/float glass manufacturing required 95% SiO_2. Although the mean silica content in Halkani sandstone is about 86.2% but it can be beneficiated by various beneficiation method except Fe_2O_3. Halkani sandstone fulfill the specification of high-grade glass as prescribed by various international agencies including American ceramics society, US bureau standard and their proposed detailed chemical specifications for silica sand for making different type of glasses Table 5 (Sundararajan et al, 2009).

Petrography

Petrographic analysis of Halkani sandstone revealed that the sediments are mainly characterized by sub-rounded to angular shape. Sediments are generally well sorted and predominantly consist of quartz (Fig. 11a-11b). Clastic sediments undergo hydraulic/mechanical sorting during transportation which considerably affects the bulk chemical composition of the resultant rocks by enriching certain minerals due to fractionation (Cullers et al, 1979; McLennan 1989; Bauluz et al, 2000; Armstrong-Altrin 2009; Singh 2009; Wu et al, 2013). Quartz is the most abundant mineral constituent which is present as monocrystalline grain while muscovite and biotite are accessory minerals. The subordinate amount of feldspar and lithic fragments in the studied samples indicate cratonic setting as well as moderate degree of chemical weathering (Akinlua et al, 2016). According to Lamar (1928) the sand is rich in silica which can be used to manufacture glass.



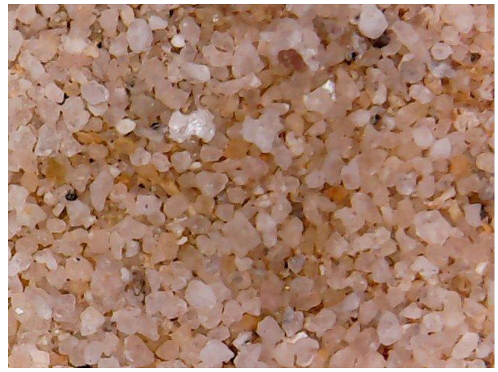


Figure 11 Showing (a) the degree of roundness. RG= Rounded grain, SRG=Sub-rounded grain, AG=Angular grain. (b) Showing the mineral composition of Halkani sandstone. Arrows showing Quartz (Q), quartz grain coated with iron oxide (Fe) and the opaque heavy mineral grain (H).

Table 3 Chemical composition of representative samples through SEM-EDS.

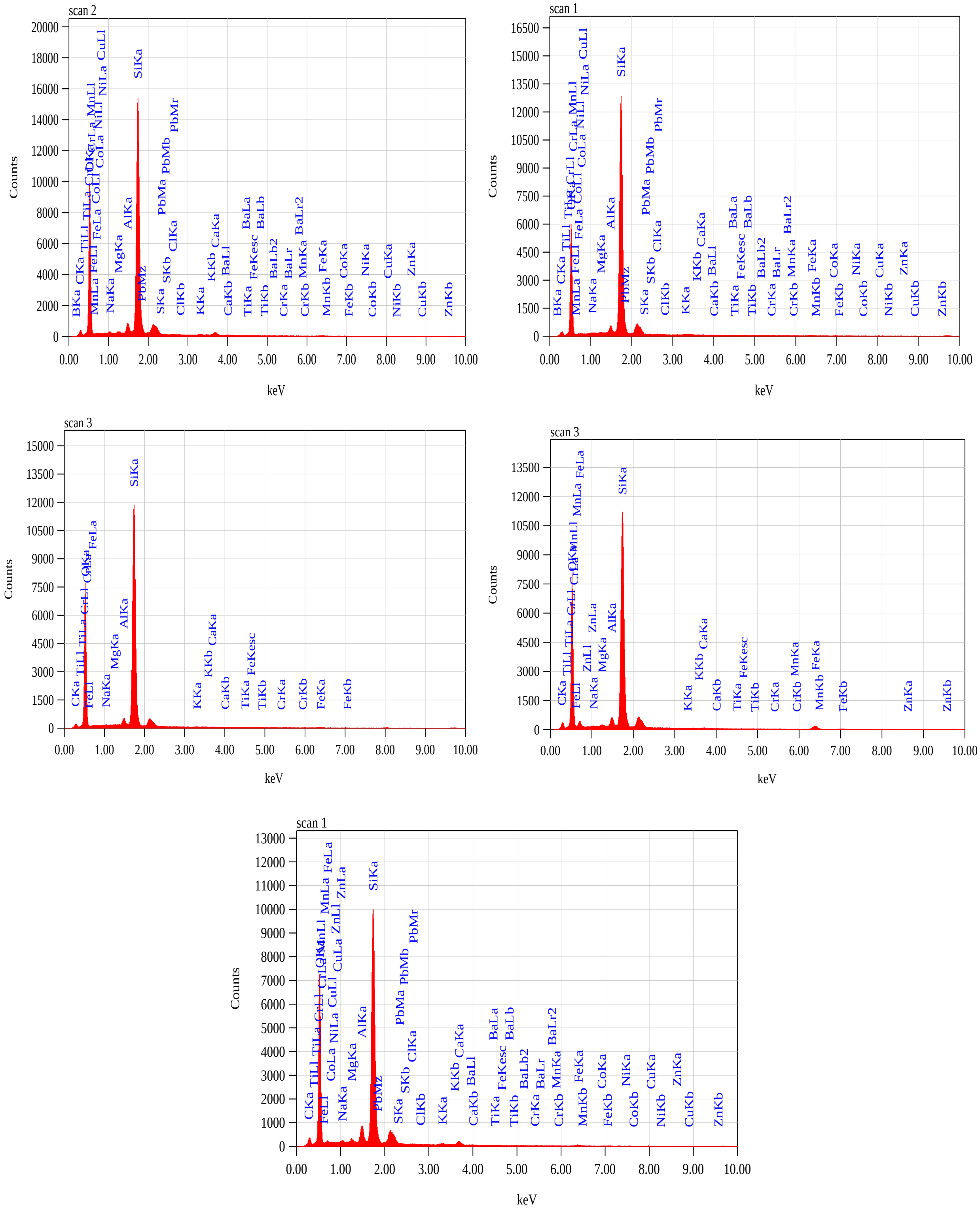
OXIDES %	S14b	S22a	S3c	S6c	S20a	Mean
SiO_2	74.9	87.3	96.5	88.9	83.2	**86.2**
Al_2O_3	2.54	5.12	2.25	3.01	1.89	**2.96**
Fe_3O_4	0.58	2.04	0.67	6.87	0.62	**2.16**
CaO	1.39	2.21	0.17	0.48	0.01	**0.9**
MgO	0.39	0.95	0.13	0.5	0.23	**0.44**
Na_2O	0.28	0.69	0.16	0.08	0.05	**0.3**
K_2O	0.34	0.54	0.08	ND	0.3	**0.32**
Cr_2O_3	0.05	0.18	ND	ND	0.17	**0.13**
ZnO	0.19	ND	ND	0.14	ND	**0.2**
CoO	ND	0.1	ND	ND	ND	**0.1**
TiO_2	ND	0.07	0.01	ND	0.19	**0.09**
CuO	0.99	0.63	ND	ND	0.65	**0.76**
B_2O_3	18.12	ND	ND	ND	12.54	**15.33**
BaO	0.03	ND	ND	ND	ND	**0.03**
NiO	ND	ND	ND	ND	ND	**ND**
MnO	ND	ND	ND	ND	ND	**ND**
PbO	ND	ND	ND	ND	ND	**ND**

Table 4 General specification of chemical composition of glass sand.

Glass quality	SiO_2%	Fe_2O_3%	Al_2O_3%	CaO/MgO%	TiO_2%
Optical glass	99.80	0.005	0.100	0.100	-
Borosilicate glass	98.50	0.05	0.50	0.20	0.012
Colorless container glass	98.50	0.150	0.50	0.50	0.100
Clear/Float glass	95.00	0.200	4.00	0.50	0.100
Insulating fibre	95.00	0.300	0.50	0.50	0.100
Amber glass	95.00	1.00	4.00	0.50	0.100
Green glass	95.00	1.00	4.00	0.50	0.100
Grain shape: Angular, round and sub-angular melt easily.					

Table 5 showing the comparison with various standards for high grade glass and glass fiber (Austin 1984).

Element Oxides	Wt %	US standard (1965)	British standard (1988)	Austin (1984) Glass Fiber	Vycor high temperature scientific glassware Austin (1984)
SiO_2	86.192	95 % (min)	98.5 % (min)	55%	96.3
Al_2O_3	2.962	4 (max)	-	14	0.4
Fe_3O_4	2.156	1 (max)	0.30 (max)	-	-
Na_2O	0.252	-	-	0.5	-
K2O	0.315	-	-	-	-
MgO	0.44	0.5 (max)	0.5 (max)	5	-
CaO	0.852	0.5 (max)	0.5 (max)	13	-
MnO	ND	-	-	-	-
ZnO	0.165	-	-	-	-
TiO_2	0.09	-	-	-	-
B_2O_3	10.43	-	-	10	2.9
CuO	0.6067	-	-	-	-
Cr_2O_3	0.11	-	-	-	-
PbO	ND	-	-	-	-
C	ND	-	-	-	-
Cl	0.12	-	-	-	-
CoO	0.15	-	-	-	-
NiO	ND	-	-	-	-



` **Figure 12** SEM-EDS micrographs showing SiO_2 as major oxides.

Conclusion

Present study has revealed that Halkani sandstone is suitable for manufacturing of various types of glass in terms of its thermal and mechanical attributes. Generally medium to fine fraction is needed for high grade glass making where Halkani sandstone qualify only as fine sediments with subordinate medium fraction. Mineral composition, slightly deviates from the standard (> 90%) in terms of silica content. Conversely, this sand is best for glass fiber which only needs 55% silica. Chemical constituents of Halkani sandstone are within permissible limits or marginally deviate from it. However, Fe_2O_3 is anomalously high which must be removed through beneficiating methods before glass making.

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