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5

6 **Abstract**

7 A kaolinitic sandstone sample from Wadi Qena deposit, the Eastern Desert of Egypt, was
8 subjected to mineralogical and chemical characterization for possible separation of kaolin and
9 silica sand concentrates. Attrition scrubbing process was applied in two different scenarios
10 either on the whole crude sample or on the separate size fractions to collect both the white
11 kaolin coating the sand grains and the sand itself. Factors affecting the process and the
12 products after attrition were optimized and evaluated. The -0.025 mm kaolin product after the
13 attrition scrubbing process assays 36.05

14

15 *Index terms*— cellular kaolinitic sandstone, classification, attrition scrubbing, fine kaolin, silica sand.

16 **1 I. Introduction**

17 In Egypt, distributions of kaolinitic sandstones rocks are present in Sinai, the Eastern Desert, and the southern
18 Western Desert, Figure 1, [1][2][3][4]. Wadi Qena is one of the largest wadies in the Eastern Desert of Egypt. It
19 is constituted from sandstones which are represented by quartz arenite, while kaolinite is the sole clay mineral
20 constituent. These sandstones are being inherited from felsic-granitic and reworked quartzose sediments and
21 transported by rivers to the basin of deposition, [5][6][7][8][9][10][11][12][13][14].

22 Kaolinite and silica sands are belonging to the group of industrial minerals, where their characteristic features
23 lie in their physical properties (e.g., fibrosity of asbestos, insulatory properties of mica, the high specific gravity
24 of barite). However, kaolinite has the chemical composition $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. It is produced by the chemical
25 weathering of aluminum silicate minerals like feldspar. The main use of the mineral kaolinite (about 50%) is
26 paper production; its use ensures the gloss on some grades of coated paper. Kaolin is also used in ceramics,
27 in toothpaste, and in paint to extend the titanium dioxide (TiO₂) white pigment and modify gloss levels. In
28 its altered metakaolin form, it is used as a pozzolan; when added to a concrete mix, metakaolin accelerates the
29 hydration of Portland cement, [15][16][17].

30 The present study is devoted towards the full mineralogical and chemical characterization of Wadi Qena
31 sandstone rock for possible separation of its main constituents: kaolin and silica sand components. Further
32 treatment of these mineral components to satisfy the requirements of the industry is the appropriate objective.
33 On the other hand, silica sands have got the most diversified use among all the non-metallic minerals deposits.
34 The white silica sands are defined as high purity sands in which the sand grains are composed entirely of
35 quartz. Impurities are very minor including for example: iron oxides, feldspars, micas, heavy minerals (zircon,
36 tourmaline), [15][16][17]. Silica is a basic material in the glass industry, ceramic and refractory industries, and
37 silicon-based chemicals. Silica sand is evaluated for industrial use on the basis of its chemical composition and
38 physical properties. However, chemical specification is of paramount importance in glassmaking, whereas grain
39 angularity and hardness are important for sandblasting, [15][16][17].

40 A kaolinitic sandstone sample was supplied through the Egyptian Geological Survey and Mining Authority
41 from Wadi-Qena deposit; northern Eastern Desert of Egypt. A representative sample of which was prepared and
42 subjected to mineralogical and chemical evaluation. The petrographic examination microscope examination of
43 the grain composition and texture are applied using an Olympus optical microscope. Powders were prepared from
44 the same sample and were subjected to phase and chemical analysis using a Philips PW 1730 X-ray generator
45 with Fe-filtered Co K α radiation, run at 40 kV and 30 mA and A Philips PW Year 2018 The attrition scrubbing

46 tests were conducted using a 5 liter Pyrex glass container of a Denver 12 flotation cell. Two attrition scrubbing
47 scenarios according to the type of feeding material were applied. The indicator of prevailing was the amount
48 of the produced kaolin product (the 25-micron product) and its grade concerning the optical properties, mainly
49 the whiteness and the brightness were determined. The first scenario was the attrition scrubbing of the overall
50 sandstone sample as received. The second scenario was to gather the 25-micron products after the separate
51 attrition scrubbing of the dry classified the +0.60 mm fraction, the -0.6+0.10 mm fraction, and the -0.10 mm
52 fraction. The attrition time optimized in this study. Other vital parameters like pulp solid% and the attrition
53 impeller speed were kept constant at the maximum predetermined levels (65% solid and 2700 rpm) throughout
54 all the experiments. The silica sand and kaolin products after the optimized attrition scrubbing process were
55 evaluated for the local industry. © 2018 Global Journals

2 III. Results and Discussion

3 a) Characterization of the Head Sample

58 The x-ray diffraction analysis of the head sample shows the presence of silica and kaolin minerals, Figure 2. It
59 contains 89.97% silicon dioxide, 6.95% alumina, 0.138% iron oxide, and 0.356% titanium oxide, Table 1. SEM
60 photomicrograph shows that the original sample is composed of large to medium quartz grains cemented with
61 white kaolin which appeared mainly as grain rimming and coatings of the silica quartz grains, Figure 3. SEM
62 photomicrograph shows also quartz grains with conchoidal fractures, straight grooves, and crescent gouges, which
63 suggests its deposition in moderate to high energy aqueous environments, [18][19][20][21]. The surface textures
64 of the quartz grains indicate that they are the product of mechanical weathering, [18][19][20][21].

65 The microscopic investigation of the sample shows heavy minerals inclusions on the sand surfaces, Figure
66 4. After the sink/float separation (using bromo form), it is noticed that black and colored particles are more
67 enriched in the fine fractions below 100 micron. These minerals are mainly rounded grains of zircon, tourmaline,
68 and rutile, Figure 4. This suggests that the deposit derivation was either from igneous or metamorphic rocks,
69 [18][19][20][21]. The presence of needle and round crystals of biotite and of fine magnetite grains was confirmed.
70 b) The Dry/ Wet Classification of the Head Sample The chemical analysis of the dry and wet classified products
71 shows great upgrading in the sand quality compared to the original head sample, Tables 2 and 3. The silica
72 content increases from 89.97% in the feed sample to 96.97% in the dry classified -0.60+0.106 mm sand product.
73 Additionally, the dry classification of the head sample helped to reduce the iron oxide content from 0.138% in
74 the feed sample to 0.065% in the dry classified product, Table 3, with removal yield reaching 53%. The sand
75 upgrading is due to the rejection of most iron oxides minerals, mainly magnetite below 100 micron.

76 In addition, the alumina content decreased from 6.95% in the head sample to 2.57% in the dry classified sand
77 product with a removal yield reaching 63%. This is due to the separation of most of the free kaolin particles
78 to below 100 micron, and in addition to the rejection of aluminum bearing minerals that are below 100 micron
79 like biotite. On the other hand, titanium oxide is reduced from 0.36% in the head sample to 0.128% in the
80 dry classified sand sample due to the separation of rutile particles by screening to below 100 micron, with 64%
81 removal yield, Table 3.

82 It is noticed that wet screening of the head sample has no effect on the sand grade despite the notable change
83 in the particle size distribution of the 0.60+0.106 mm products before and after the wet screening, Table 3. This
84 change in the particle size distribution is due to the disintegration of the sandstone accumulations in the +0.60
85 mm fraction which represents 11.74% by overall weight of the head sample by just simple water showering. This
86 data illustrates how much the clusters fragility of the present sandstone sample is, while it does not need any
87 crushing process to disintegrate into individual grains. However, this water showering is not enough to take off
88 the kaolin coatings that cover the surfaces of the silica grains, and this may be the reason why the grade of the
89 washed sample is not affected by the water washing process, Table 3.

4 c) Attrition Scrubbing of the Sample

91 After much attrition scrubbing exploratory tests on the present kaolinitic sandstone sample, it shows that the
92 optimum attrition time for all tested samples is 3 minutes in two steps (two min followed by 1 min). Screening
93 on 100 microns sieve with enough water showering of the over screen product after attrition scrubbing for 2 min
94 shows to be enough to detach the kaolin coatings away from the sand surface. Attrition Scrubbing of the 100+
95 micron washed sand for another 1 min is sufficient to attain complete cleaning of the sand surface and to recover
96 the most amount of the white kaolin that coat the surface of the sand grains, Tables 4-5. The 100-micron kaolin
97 product is further screened on 25 microns sieve to reject most of the fine silica, also of the most heaviest and
98 colored oxides that found in the range from 100 microns to 25 microns, Tables 4-5.

99 On the other hand, the cumulative weight percent of the produced -0.025 mm kaolin product after the attrition
100 scrubbing of the fractionated sand sample is $1.65+4.79+4.39= 10.83\%$ after the attrition scrubbing of the size
101 fractions, +0.60 mm, -0.10 mm and 0.60+0.10 mm fractions, respectively, Table 5.

5 i. Evaluation of the kaolin product

The optical properties of these kaolin fractions after the attrition scrubbing of the fractionated sand sample show lower values compared to that of the kaolin product after the attrition scrubbing of the overall sample without fractionation, Table 6. However, the kaolin product obtained after the attrition scrubbing of the 0.60+ mm fraction shows excellent optical properties measures, but it is of a relatively low weight percent compared to the head sample, Tables 5 and 6.

However, the weight percent of the produced 25-micron kaolin product after the attrition scrubbing of the head sample reaches 9.95% by overall weight, with optical properties measures reaching 79.30% brightness 85.97% iso-brightness, 92.72% whiteness, and 4.98 yellowness, Table 7.

Particle size distribution of kaolin shows that its D50 is 12.36 micron and the D80 is 23.51 micron, Figure 4. The XRD analysis of this kaolin product shows sharp narrow kaolin peaks reflect a high degree of ordering, Figure ???. Additionally, its chemical analysis shows that it contains 36.05% alumina, 47.72% silica, 0.62% iron oxide and 1.67% titanium oxide, Table 8. These chemical and optical properties specifications are matching the needs of glass and ceramics industries. However, this kaolin product needs lowering its iron and titanium oxides contents to match advanced applications like paper, cosmetic and medical industries. This issue will be covered in a separate study.

Scanning electron microscope investigation of the 25-micron kaolin product records this kaolin as vermicular, euhedral and pseudo-hexagonal plates (booklets), Figure ???. The hexagonal kaolinite plates are found either as discrete individual platelet or associated with the stacks in varying sizes (up to 30 micron). The majority of kaolinite particles show parallel orientation and have face-to-edges fluctuation.

The SEM pictures of the attrition sand product show the presence of mineral remains inside the cracks cavities of the sand grains surfaces, Figure 7. In such cases, the use of ultrasonic cleaners in high-frequency range may provide cleaning for the sand surfaces where no other means of agitation is effective. The energy imparted by ultrasonic is aggressive and specific for such cases, [22]. The microscopic examination of the attrition sand product shows varieties of colored and refractory minerals still present after the attrition process. These minerals include biotite, magnetite, rutile, zircon and tourmaline minerals. The iron oxide and alumina contents decrease from 0.138% and 6.952% in the feed to 0.036% and 0.119% in the attrition product, with removal yields reaching 74% and 83%, respectively, Table 9. The particle size distribution of the attrition product is depicted in Table 10. This product matches the sheet and Paper industries.

6 IV. Conclusion

Results show that the kaolinitic sandstone of Wadi Qena, Eastern Desert, Egypt contains notable amount of white kaolin coating the silica grains. The preferable scenario to detach this kaolin is to apply an intensive attrition scrubbing process for the whole head sample at 65% pulp solid density, 2400 rpm impeller speed for 3 min in two attrition steps separated by proper water washing step on 100 microns screen. The attrition process yields 25-micron kaolin of about 9.50% by weight of the sample. This kaolin product shows good optical properties which makes it acceptable for many domestic applications. However, it needs to minimize its iron and titanium oxides contents to match advanced applications, e.g. pharmaceutical, porcelain, and paper industries which will discuss in another issue.

On the other hand, the dry classification of the sandstone sample acts remarkable improvement in the sample grade. Further quality improving occurs after the attrition scrubbing of the whole sample. The iron and aluminum oxides decrease from 0.138% and 6.952% in the feed sample to 0.036% and 0.119% in the attrition sand product, with removal yields reaching 74% and 83%, respectively. The chemical and particle size distribution specifications of this product match the 4th grade level acceptable for plate and sheet glass industries. The attrition product needs further surface cleaning to remove the minerals remains found inside the sand surface cracks using power ultrasound treatment. Moreover, the attrition sand is in need to further processing to remove iron and heavy oxides via high intensity magnetic separation or anionic froth flotation to reach the chemical specifications of advanced types of glass applications.

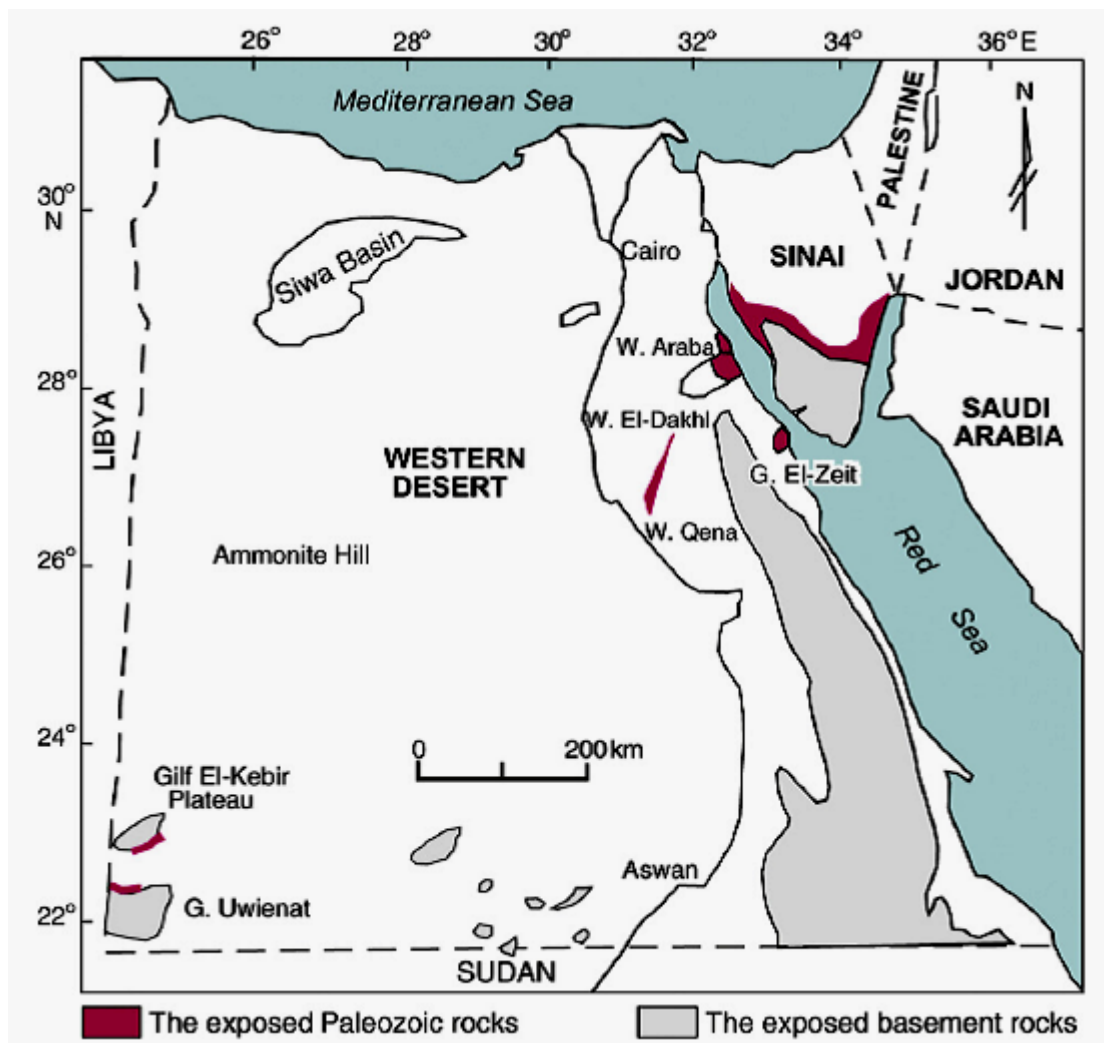
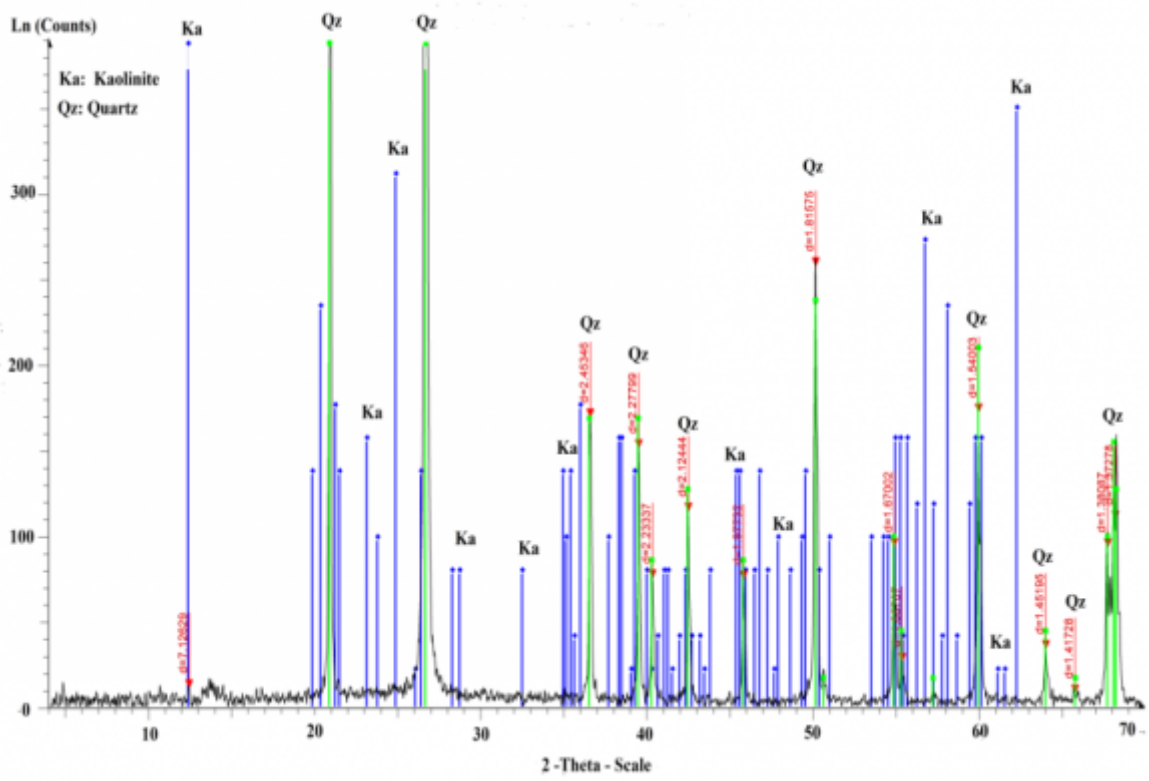
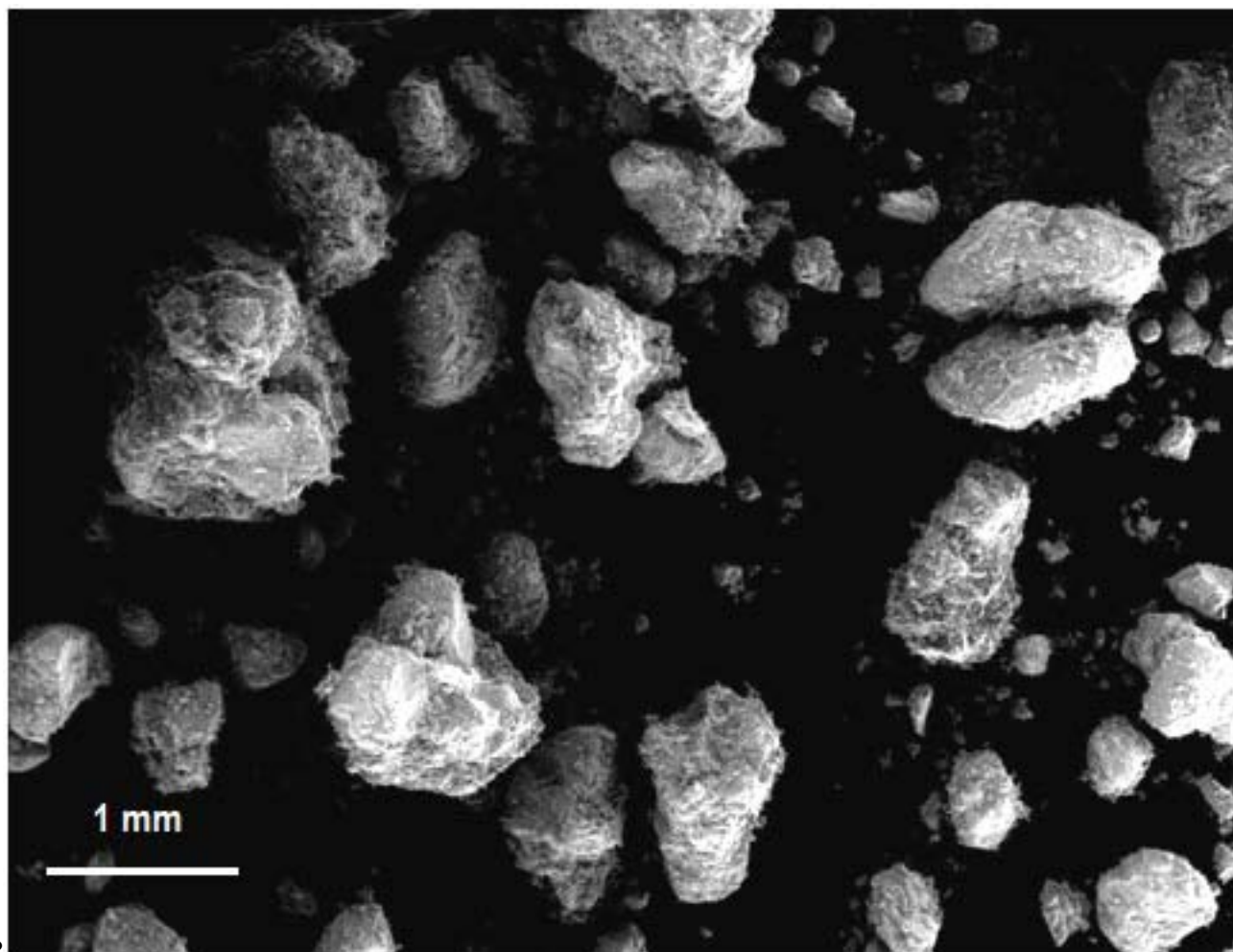


Figure 1:



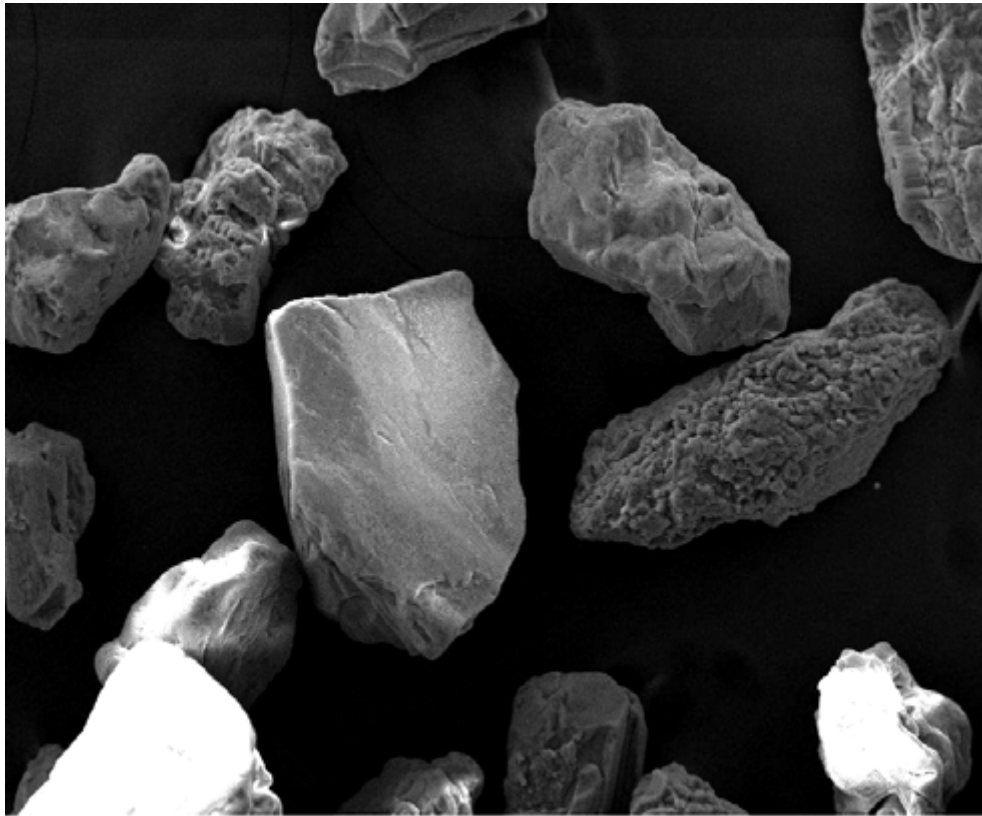
1

Figure 2: Figure 1 :



2

Figure 3: Figure 2 :



3

400 μ m

X 150

Figure 4: Figure 3 :

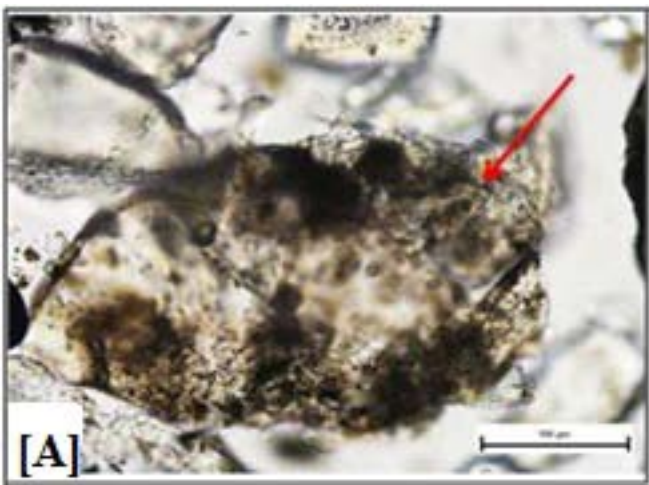
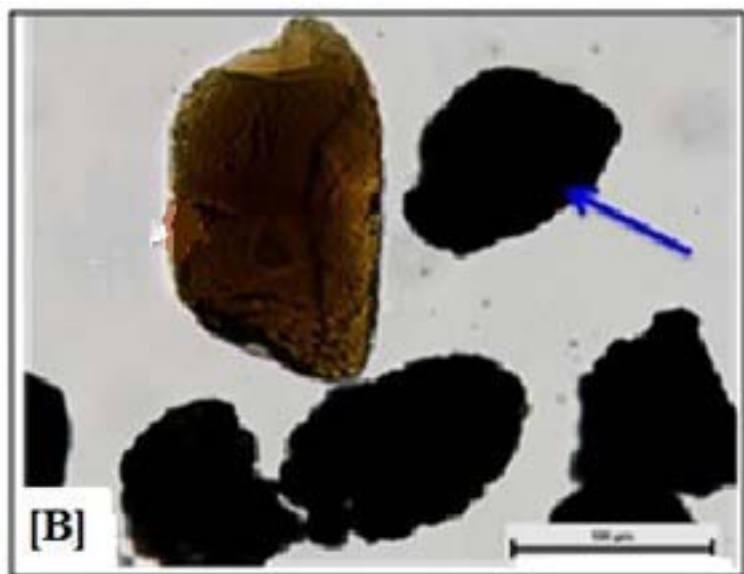
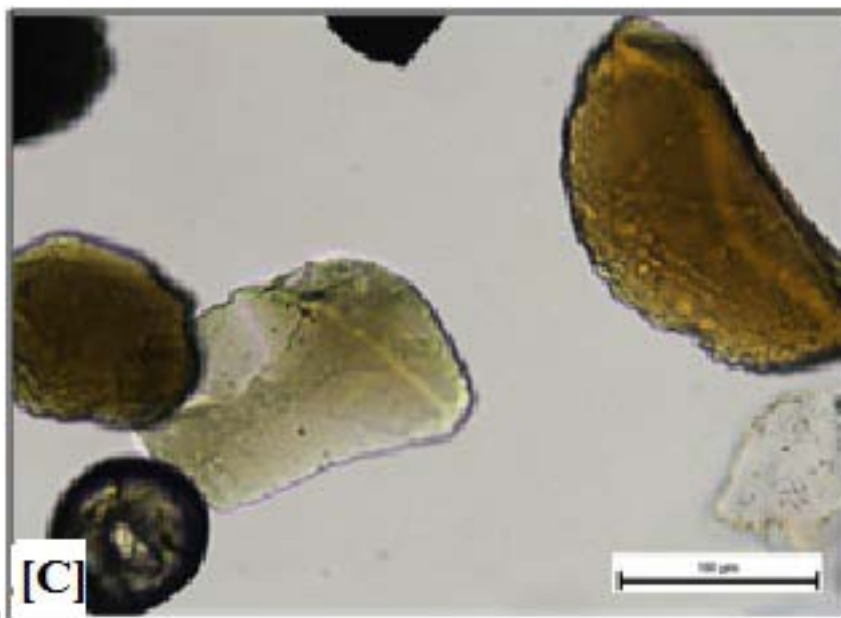


Figure 5:



4

Figure 6: Figure 4 :



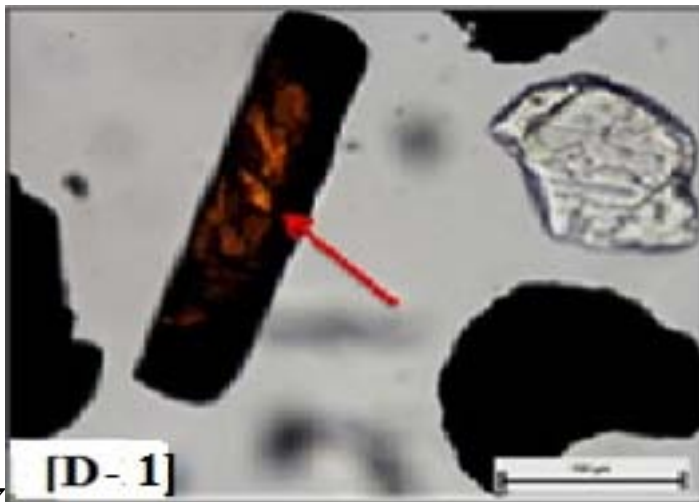
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Figure 7: Figure 4 :



56

Figure 8: Figure 5 :Figure 6 :



7

Figure 9: Figure 7 :

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Figure 10:

1

Constituent	Wt. %
SiO ₂	89.968
Al ₂ O ₃	6.952
Fe ₂ O ₃	0.138
TiO ₂	0.356
SrO	0.021
CaO	0.192
Na ₂ O	0.065
K ₂ O	0.022
P ₂ O ₅	0.061
Cl	0.072
SO ₃	0.213
ZrO ₂	0.040
L.O.I	1.90

Figure 11: Table 1 :

2

Size fraction, um	Dry Classification		Wet Classification	
	Wt., %	Cum. wt., retained %	Wt., %	Cum. wt., retained %
+600	11.74	11.74	1.32	1.32
-600 + 106	79.76	91.50	87.28	88.60
-106+45	2.37	93.87	2.53	91.13
-45+ 25	0.98	94.85	1.42	92.55
-0.025	5.15	100.00	7.45	100.00
Total	100.00		100.00	

Figure 12: Table 2 :

3

Constituent	Wt. % (dry classified)	Wt. % (wet classified)
SiO ₂	96.97	97.050
Al ₂ O ₃	2.568	2.530
Fe ₂ O ₃	0.065	0.051
TiO ₂	0.128	0.128
SrO	0.008	0.008
CaO	0.070	0.075
Na ₂ O	0.021	0.021
K ₂ O	0.007	0.008
P ₂ O ₅	0.017	0.015
Cl	0.023	0.021
SO ₃	0.056	0.054
ZrO ₂	0.036	0.036

Figure 13: Table 3 :

4

Size fraction, um	Operational wt., %
+600	1.35
-600+106	84.25
-106+40	3.00
-40+25	1.45
-25	9.95
Total	100.00

Figure 14: Table 4 :

Figure 15: G

5

Size fraction, mm	Wt., %					
	Opt.	[A] overall	Opt.	[B] overall	Opt.	[C] overall
+0.60	4.11	0.48	—	—	—	—
-0.60+0.106	72.11	8.47	—	—	92.83	74.02
-0.106+0.045	5.53	0.65	32.22	2.37	1.22	0.97
-0.045+0.025	4.22	0.50	11.64	0.98	0.46	0.36
-0.025	14.03	1.65	56.14	4.79	5.49	4.39
Total	100.0	11.74	100.0	8.50	100.0	79.74

Figure 16: Table 5 :

6

Sample	Brightness%	Iso-brightness%	Whiteness%	Redness%	Yellowness%	D 52 , um	D 80 , um	D 96.7 , um	
A	79.45	86.40	92.95		0.25	5.08	11.11	21.12	36.73
B	75.09	83.07	91.14		0.34	5.96	12.36	26.16	45.22
C	77.00	85.00	92.20		0.36	5.86	11.11	23.51	40.81

Figure 17: Table 6 :

7

Property	Measure, %	Property	Measure, %
Brightness	79.30	Yellowness%	4.98
Iso-brightness	85.97	D 52 , um	12.36
Whiteness%	92.72	D 80 , um	23.51
Redness%	0.25	D 96.7 , um	40.89

Figure 18: Table 7 :

6 IV. CONCLUSION

8

Constituent	Wt.%	Constituent	Wt.%
SiO ₂	47.72	K ₂ O	0.04
Al ₂ O ₃	36.05	P ₂ O ₅	0.21
Fe ₂ O ₃	0.62	Cl	0.04
TiO ₂	1.67	SO ₃	0.09
CaO	0.32	ZnO	0.01
MgO	0.16	ZrO ₂	0.05
Na ₂ O	0.08	Cr	145 ppm
SrO	0.133	L.O.I	12.8

Figure 19: Table 8 :

9

Constituent	Wt.%
SiO ₂	99.754
Al ₂ O ₃	0.119
Fe ₂ O ₃	0.036
TiO ₂	0.038
CaO	0.023
P ₂ O ₅	0.006
Cl	0.017
SO ₃	0.008
ZrO ₂	0.018

Figure 20: Table 9 :

10

Size fraction, mm	Wt.%	Cum, wt.% retained
-0.6	5.56	5.56
-0.420	43.18	48.74
-0.250	16.08	64.82
-0.210	22.22	87.04
-0.160	12.96	100.00
Total	100.00	

Figure 21: Table 10 :

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