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Quartz sand beneficiation using magnetic and electrostatic separation to glass industries

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Abstract

Quartz sand of Fortuna formation was assigned to the Oligo-Miocene. This formation outcrops in Central Tunisia, particularly in the Ain Bou Morra area. The grain particle size ranges from fine to medium. The morphoscopic analysis shows that the useful fraction (100-630μm) consists essentially of transparent quartz grains. The mineralogical study of samples after separation in heavy liquid indicates that they contain a small amount of heavy minerals such as: tourmaline, zircon and staurotide. The X-ray diffraction analysis of the total rock revealed that quartz is the major mineral constituent of sand. Chemical analysis shows high content of SiO_2. Coloring elements (Fe_2O_3) and (TiO_2) are slightly elevated. The study aim was to remove impurities from silica sand, in order to upgrade quartz sands and to produce material that has a higher potential value for industrial manufacturing processes. Several processing physical techniques (attrition, gravity, magnetic and electrostatic separation) have been developed. The obtained material after treatment was characterized using Atomic Absorption Spectroscopy (AAS) and Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). Chemical results through the combined techniques show a significant increase of impurities (such as Fe, Ti, Cr ...) and a significant increase of SiO_2. The final concentrate achieved 99.99 % SiO_2, 8 ppm Fe_2O_3 and 6 ppm TiO_2 was obtained, at the optimum operating conditions, from an ore containing about 98.8% SiO_2, 0.16% Fe_2O_3 and 0.05% TiO_2. The treated sand has been found to be a satisfactory material conforms to the requirements of optical glass, crystallaboratory glass and photovoltaic cells.

Keywords: Attrition, Electrostatic and magnetic separation. Quartz sand.

1. Introduction

Silica sand industry in Tunisia has been growing rapidly due to increased demand from civil engineering, pharmaceutical practices, chemical, foundries, glass, ceramic, electronics and photovoltaic industries. However, the glassmaking is an important component in the glass production accounting for around 65 to 70% wt of total raw material input.

The specifications made on glassmaking sands (Harben and Kuzvart 1997) are defined essentially by their chemical composition (SiO_2, Al_2O_3, Fe_2O_3 and TiO_2) and by the useful granulometric fraction (0.1 to 0.6 mm). A high content of SiO_2 which is more than 98% is combined with low impurities (%Fe_2O_3 must be lower than 0.2%). This kind of raw sand, called extra-siliceous sand is very abundant in Tunisia, especially in Oligocene and Miocene outcrops. Different authors have been studied the characterization of these sand deposits (Griffiths 1987; El Maaoui 1993; Jouirou 1981; Louhaichi 1981; Trabelsi 1988; Jamoussi 1991; Added 2005; Ben Fradj 2010). However, few works carried out on the purification and beneficiation process (Aloui, 2010; Gallala et al. 2009; Gallala 2010; Gaied & Gallala 2011)

Depending on the degree of purification described can hold two treatment schedules, which were tested in this study.

• The first schema contains the size classification before and after attrition followed by a dry magnetic separation.

A wet screening on 1.7 to 1mm before attrition to remove large and mid-large quartz coated tablets which can cause mechanical problems within the attrition cell.
A classification after attrition ranging from 0.1 to 0.63 mm was used, in order to recover the useful fraction and remove the fine fraction below 0.1 mm. The latter has contents in harmful elements significantly higher than the coarse fractions.
This scheme allows the preparation of purified sands with iron contents of about 300 to 400 ppm and a 68% weight yield for Aquitania sand from Ain Bou Morra.

- The second scheme includes more gravity separation, between the attrition operation and high intensity magnetic separation wet and still followed by electrostatic separation. This scheme was applied on three composite samples of sand Ain Bou Morra helped prepare sands much more refined, with iron content in the order of 9ppm and a weight of 76% yield.

2. Geological Setting

The study area is located in the region of Ain Bou Morra. It is 20 Km from west of Sbikha village (governorate of Kairouan, central Tunisia.).
The site is located east of the sub-meridian structure Boudabouss. The area is covered by the geological Djebibina map.
In this region the series show outcrop of Tertiary age deposits .These deposits are affected by sub-meridian direction of wrinkles. The sands studied belong to the upper Fortuna formation of Aquitanian age.
The series are composed of three lithological units from the bottom to the top (Figure 2):

- Lower unit: it shows 30 m thick sand-clay alternations covered by a large mass of misclassified sand that exceeds 70 m thick. Indeed, this basal series is in the form of consolidated sandstone rock benches with a general rate of granular decreasing sequences stratified sandstones.
- Middle unit: with 200 m thick, it is characterized by medium particle size sand with cross-stratification.
- Upper unit: with 345 m thick, it is characterized fine sand very ranked well.

The sands are organized in decreasing size sequences with coarse sand quartz at the bottom and finer sand at the top of each sequence.
The sequences are intercalated by centimetric clay layers

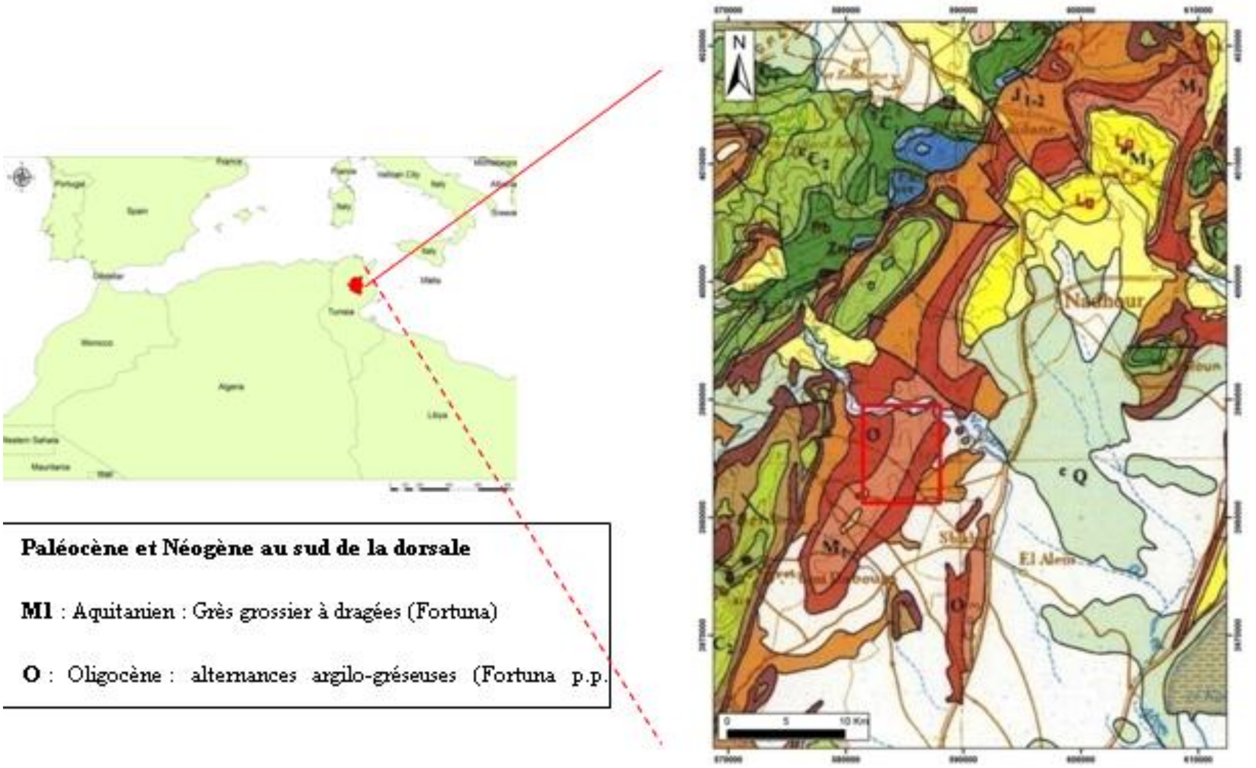
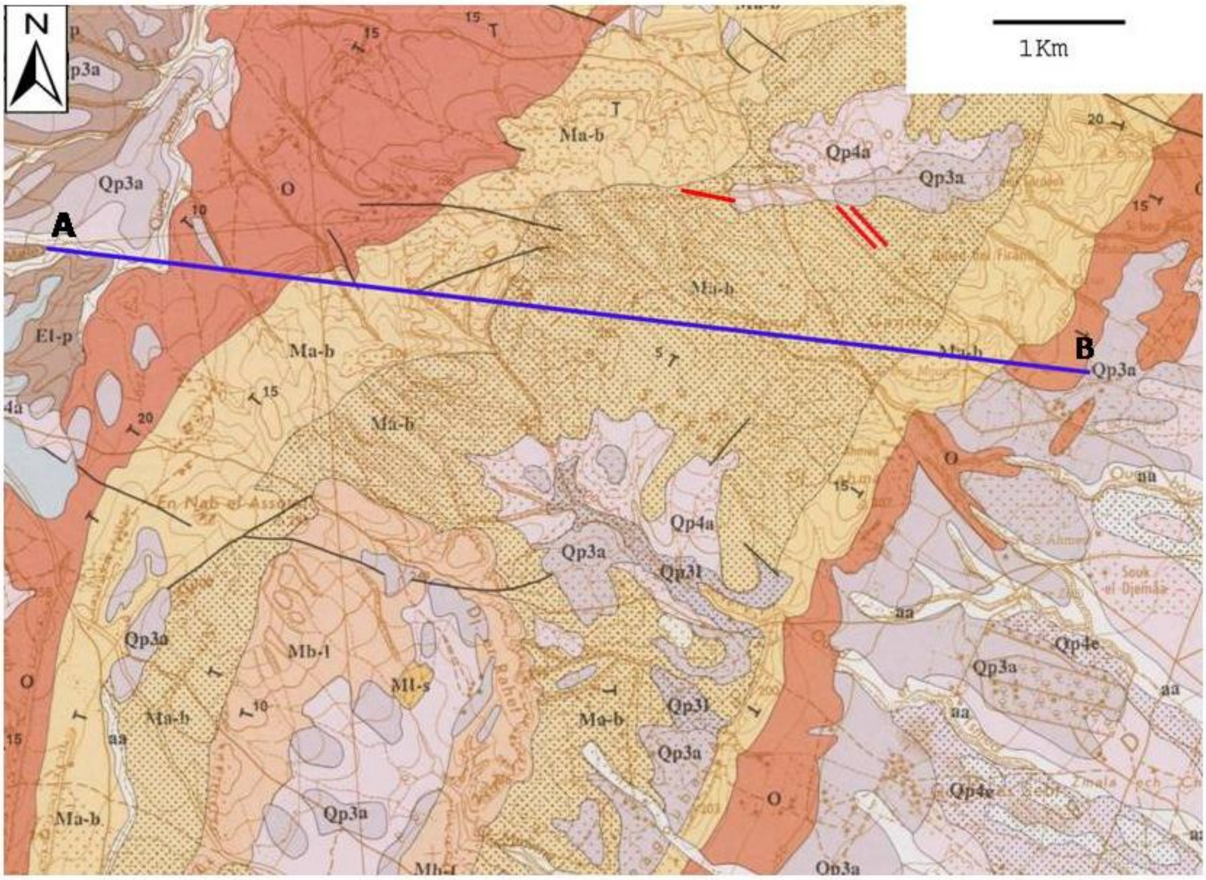


Figure 1 : Location of the study area on an extract of the geological map 1/500 000 of Tunisia



Location of the studied samples.

Ml – s : Langhien – Serravallien, Clay interbedded of sands (MAHMOUD). **Mb –I : Burdigalien supérieur – Langhien,** Sandy limestone with bioplaste (AIN GRAB). **Ma –b : aquitanien – Burdigalien** a- coarse sandstone with quartz dragees (EL HAOURIA higher), b- Alternating sandstone and clay (EL HAOURIA lower). **O : Oligocène** Clay interbedded with sands and limestones

Figure 2 : Location of the study site at the geological map Djebibina of 1:50 000.

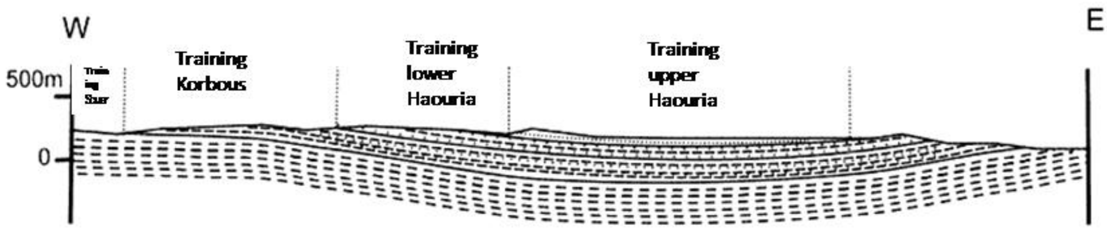


Figure 3 : Geological section in the region of Ain Bou Morra

3. Material and methods

Sand samples were collected by making grooves perpendicular to the outcrops and after etching the surface. The samples were mixed to prepare a fairly representative sample of each faces. The obtained sample has undergone several quartages to obtain similar samples with equal amount for analytical processing.

The representative ore sample is obtained from Ain Bou Morra Province, Tunisia. For the determination of granulometric distribution, standard sieves from the series "AFNOR" were used.

Major elements were analyzed by Atomic Absorption Spectrophotometer (AAS) "Perkin Elmer" 3300. In addition for monitoring minor and trace elements, the Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) (ULTIMA-C) was employed. The mineralogical analysis was carried out using stereomicroscopy. petrographic microscope and X-ray diffraction "X' Pert Pro MPD PANalytical" using Cu Kα radiation operating at 40KV and 20mA were used.

The heavy minerals separation was carried out by the standard tetrabromoethane technique (specific gravity 2.96). In this case, the attrition was done using Wemco cell (sand scrubber).

This process consisted of conditioning the sample at 70% solids during 15min. Size fractions from +0.1 to 0.63 mm were used for gravity separation by shaking table. Dry magnetic separator (15000 Gauss), wet high intensity magnetic separator (20,000 Gauss) and electrostatic separator (25 to 30KV) from Carpco were respectively used for magnetic separation and electrostatic separation tests as well .These two tests were carried out at the laboratory of Liege University.

4. Results and discussion

4.1 First method of treatment

The first method includes three stages: the classification (screening) before and after attrition followed by a dry magnetic separation.

4.2 Raw Sand characterization

4.2.1 Mineralogical analysis

The observation under a binocular microscope shows transparent grains with irregular shape. About 99% of the grains are formed by small quartz grains.

The raw samples under the binocular microscope, X-ray diffraction analysis: were conducted XRD reveals the dominance of quartz phase (3.34 Å) for the analysis of medium sand samples.

However XRD analysis for the fraction > 2µm identified the presence of kaolin and illite clay.

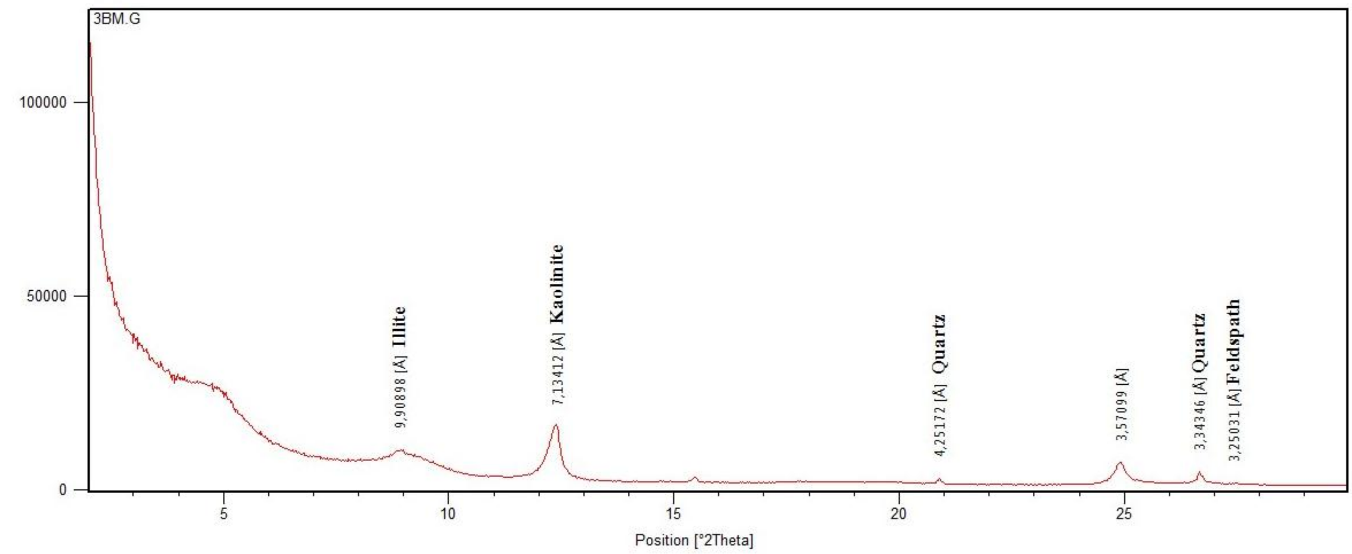


Figure 4 : X ray diffractogram clay treated with ethylene glycol

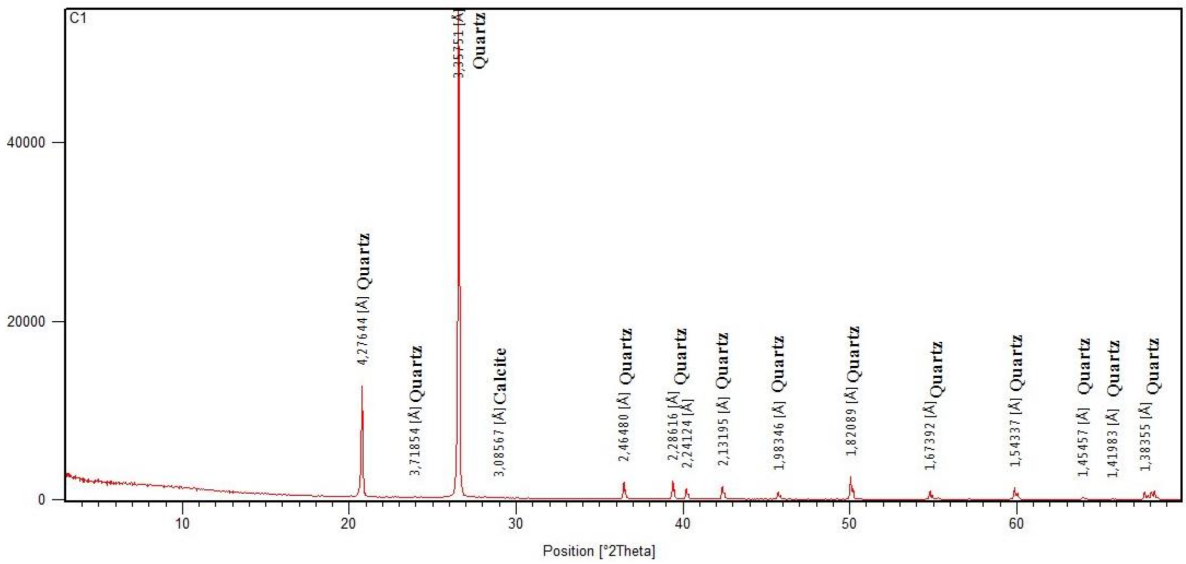


Figure 5 : X ray diffractogram of clay heated at 550°C

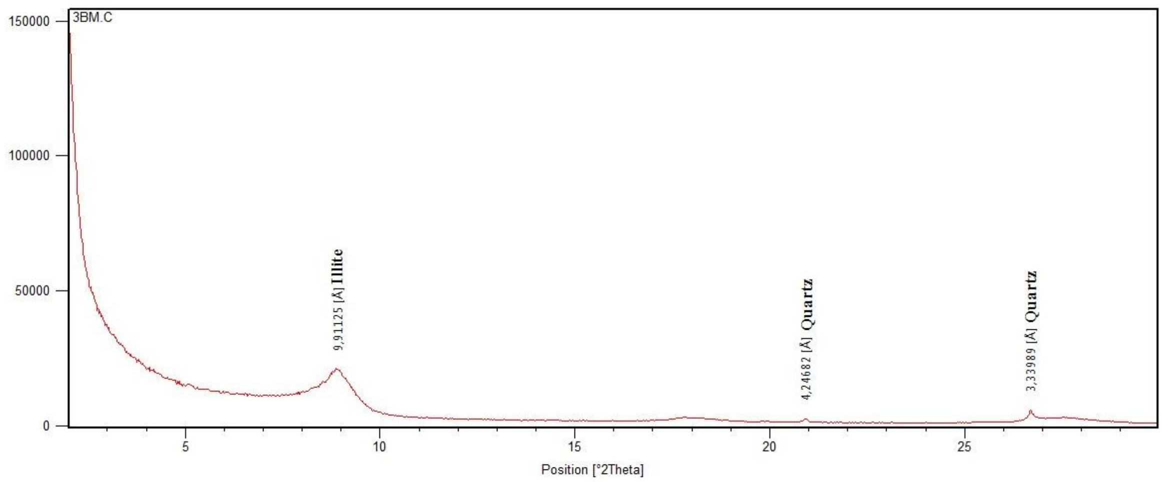


Figure 6 : X ray diffractogram powder of raw sample 1

4.2.2 Chemical and grain size analysis

Results of chemical analyses (Table 1) reveal that quality of silica sand is reasonable but some high impurities make uncertainty to produce high grade glass or photovoltaic cells. Major elements, mainly (SiO_2), ranges from 98.69 % to 99.55wt% which gives an extra siliceous character for the sand (Table 1).

Although contents, in some samples, of Al_2O_3 (0.25 to 0.47 wt %), Na_2O (0.012–0.017 wt%), K_2O (0.11–0.17 wt%) are not tolerable, but it is possible to remove or decrease .

These elements which are concentrated in the clay fractions. Major impurities, qualified as penalizing agent in the glass industry, mainly Fe_2O_3 and TiO_2 range respectively from 0.12 to 0.17 wt% and from 0.033 to 0.08 Wt%. These contents are outside the specifications for high grade glass. In order to obtain satisfactory product, it is primordial to upgrade the raw materials.

Table 1 : Chemical analysis of raw sand samples

Sample	SiO_2 %	Al_2O_3 %	CaO %	Fe_2O_3 %	K_2O %	MgO %	Na_2O %	TiO_2 %	Cr (ppm)	Cu (ppm)
Sample 1	99.39	0.25	0.07	0.12	0.11	0.010	0.012	0.033	9	8
Sample 2	99.17	0.29	0.09	0.15	0.13	0.015	0.017	0.04	10	9
Sample 3	98.69	0.47	0.11	0.17	0.17	0.07	0.016	0.08	9	9

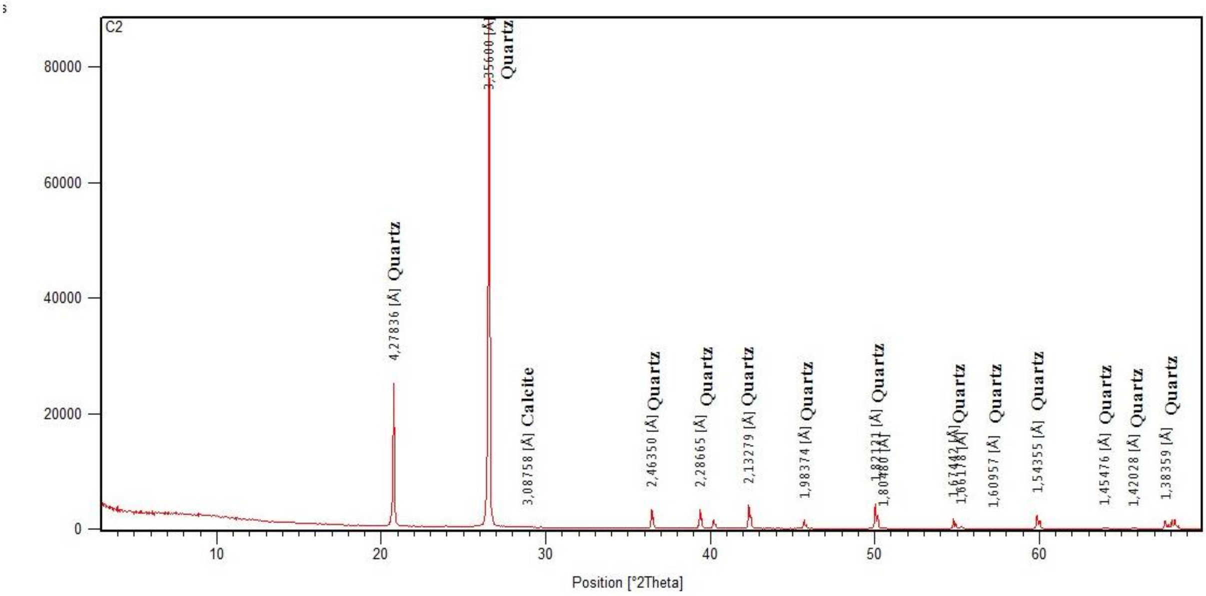


Figure 7 : X ray diffractogram powder of raw sample 2

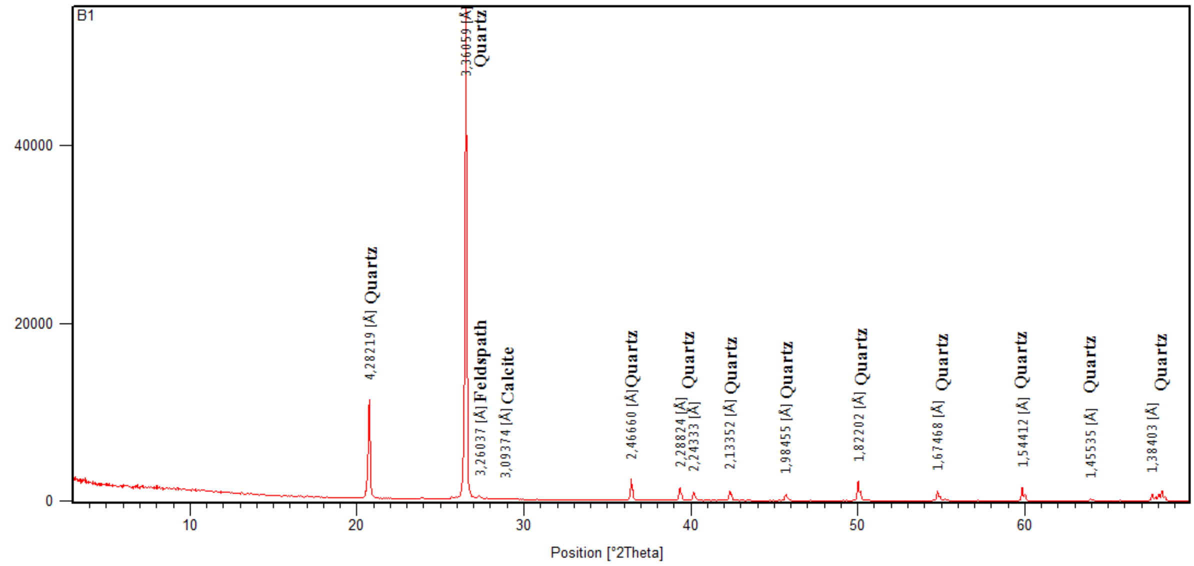


Figure 8 : X ray diffractogram powder of raw sample 3

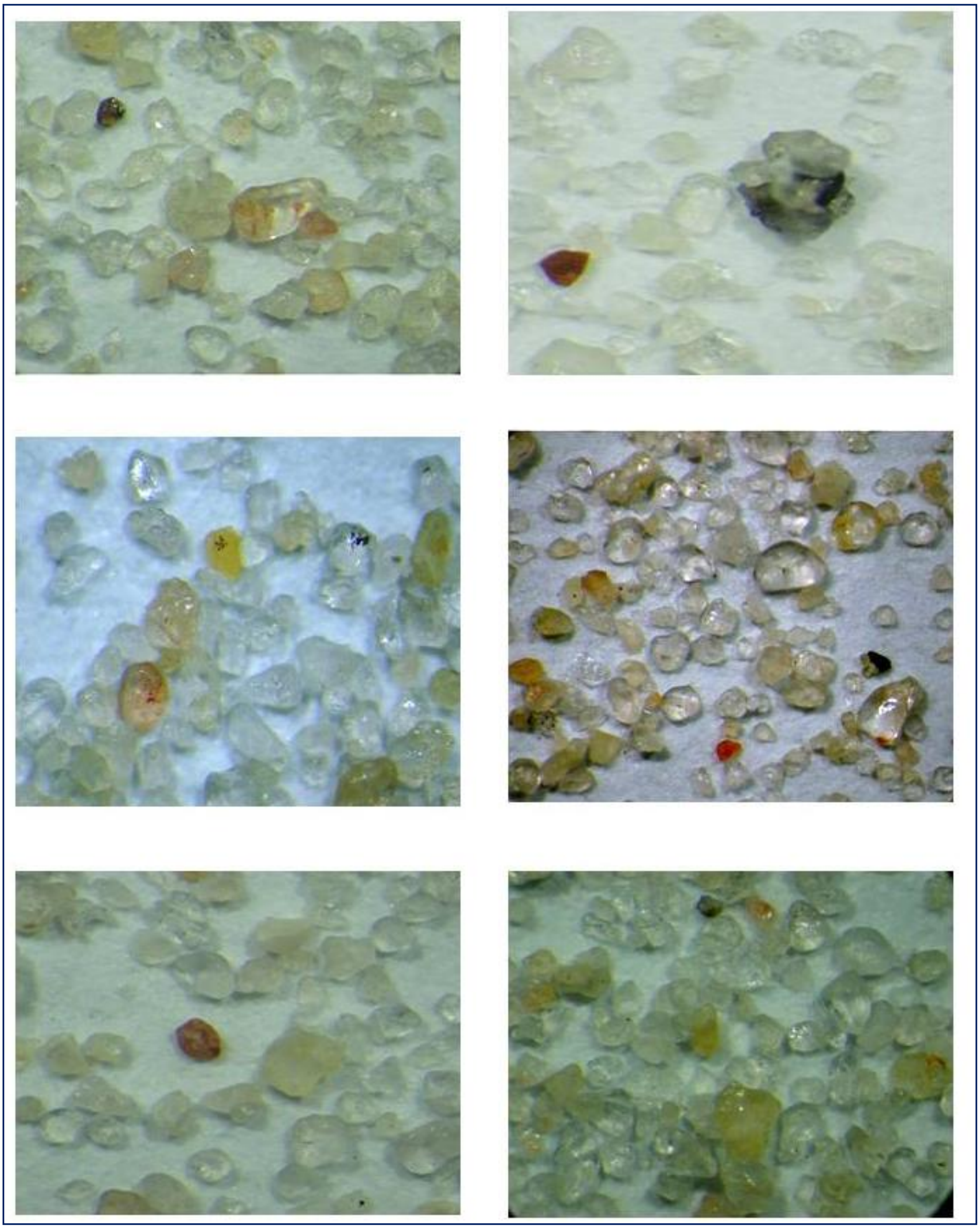


Plate 1 : photos of Mineralogical identification of the conductive portion of Fortuna sand Ain Bou Morra

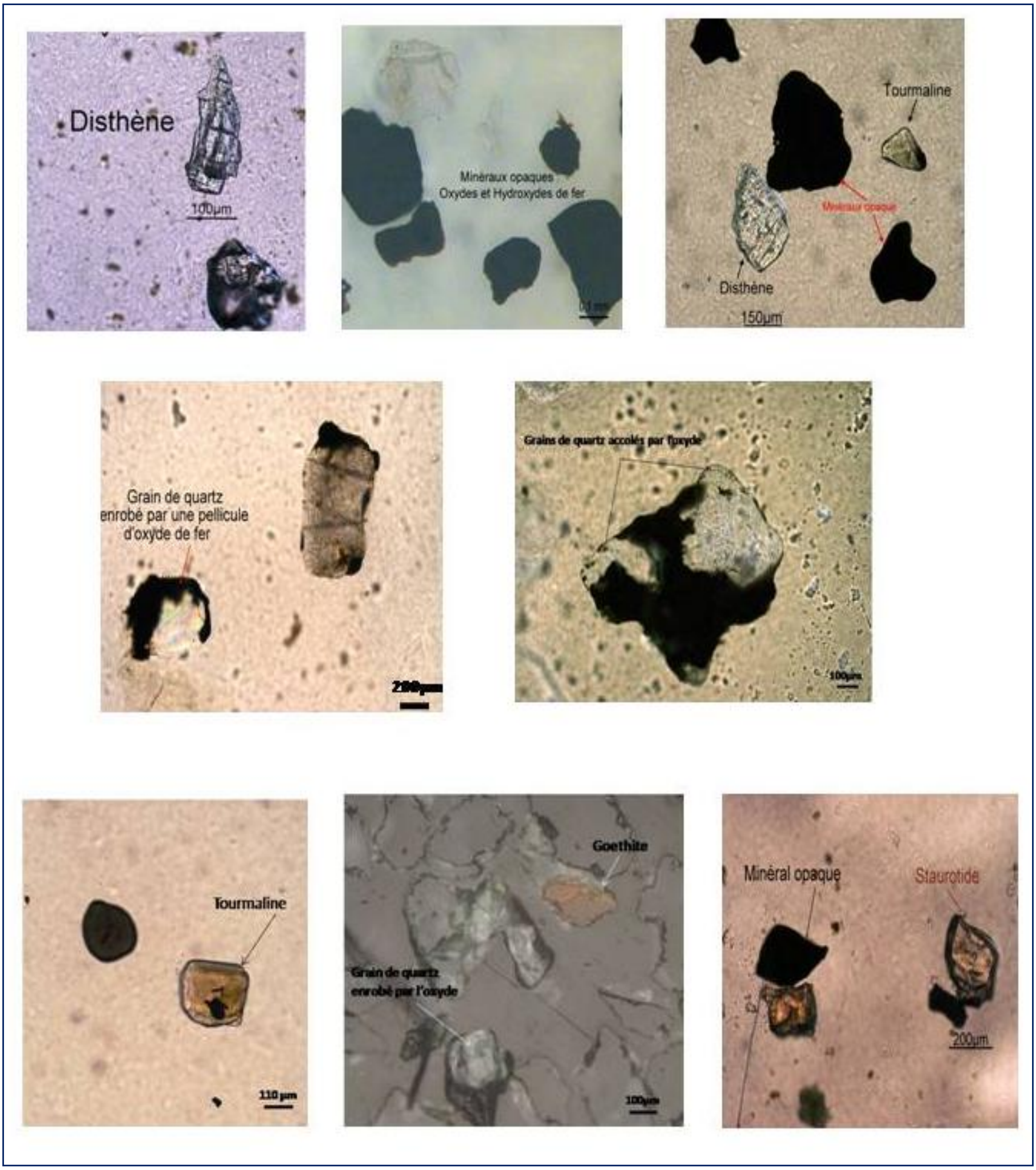


Plate 2 : Mineralogical identification of the dense fraction of Fortuna sand from Ain Bou Morra

4.2.3 Physical treatments

The raw fraction (-0.63+0.1mm) is suitable for the manufacture of flat glass and other types of white glass. However, to make high-grade silica sand an additional physical treatment is necessary comprising the following successive stages:
The first schema contains the size classification before and after attrition followed by a dry magnetic separation attrition and electrostatic separation. The results of the final product are (Table 2):

Table 2 : results of chemical analysis of the final product after treatment by attrition and dry magnetic separation

Sample	SiO_2 %	Al_2O_3 %	CaO %	Fe_2O_3 %	K_2O %	MgO %	Na_2O %	TiO_2 %	Cr (ppm)	Cu (ppm)
Sample 1	99.51	0.14	0.03	0.031	0.11	0.0072	0.013	0.01	nd	nd
Sample 2	99.39	0.12	0.05	0.029	0.10	0.0061	0.012	0.012	nd	nd
Sample 3	99.36	0.11	0.026	0.022	0.09	0.0073	0.015	0.01	nd	nd

nd: not detected

For the three studied samples, the purified fraction after attrition and dry magnetic separation is the available size fraction between 0.1et 0.63mm.
Purified samples show silica content of 99.36%.
The contents of the most harmful impurities decreased after treatment and may have an iron content between 0.02 and 0.031%, a content of 0.11 to 0.14% for alumina, a content of 0.01 % of titanium; chromium being not detected.

The second scheme includes more gravity separation, between the attrition operation and wet high intensity magnetic separation (WHIMS) and followed by electrostatic separation.
To reach the requirements of high-quality sand industry, the sand should be further purified with silica grains devoid of other minerals or any contaminants. The final product must include a total contaminant level <10 ppm (Outotec, 2007). In order to reach this specification the high voltage electrostatic separation was applied.
Practically, the separator with different voltage value is used. The results are given in table 3.

Table 3 : Variation of% weight and the% of Fe2O3 of the fraction non-conductive fraction

VOLTAGE KV	% Weight of non-conductive fraction	% Fe2O3
10	42	0.028
15	72	0.019
20	87	0.003
28	99	0.0009
30	82	0.007

Table 4 : distribution of weight and the% of Fe2O3 according to the fraction not conductive voltage variation (%)

VOLTAGE KV	% Weight of non-conductive fraction	% Fe2O3
10	40	0,03
15	71	0,025
20	89	0,0028
28	98	0,0001
30	79	0,0025

Table 5 : distribution of weight and the% of Fe2O3 according to the fraction not conductive voltage variation (%)

VOLTAGE KV	% Weight of non-conductive fraction	% Fe2O3
10	37	0,029
15	66	0,023
20	81	0,004
28	94	0,0001
30	80	0,002

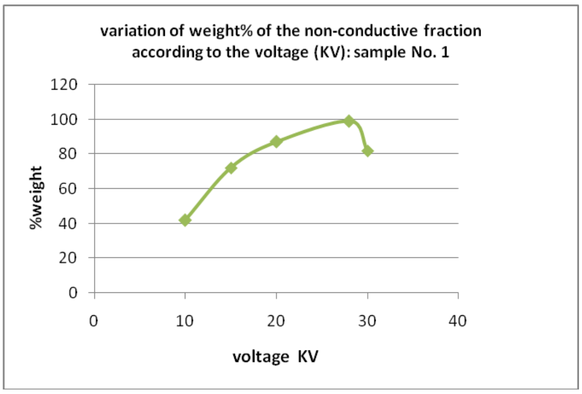


Figure 9. Curve of variation of the weight% of the non-conductive portion in function of the voltage (kV): case of the average sample Am1.

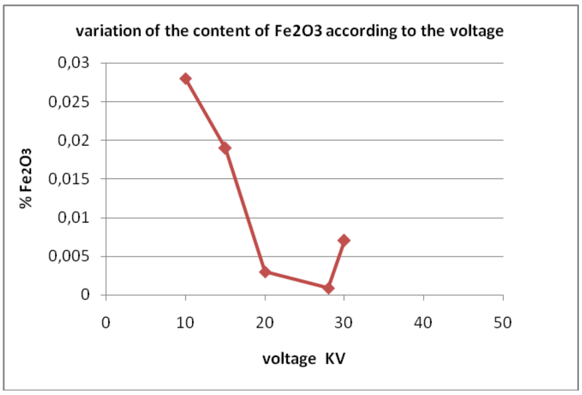


Figure 10. Variation curve of the Fe2O3 content in function of the voltage (kV) If the average sample AM1.

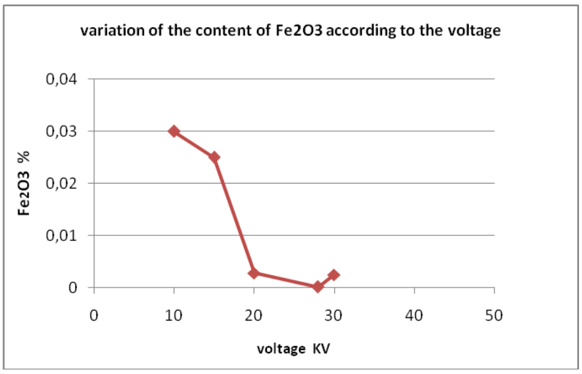


Figure 12. Variation curve of the Fe2O3 content in function of the voltage (kV) If the average sample AM2.

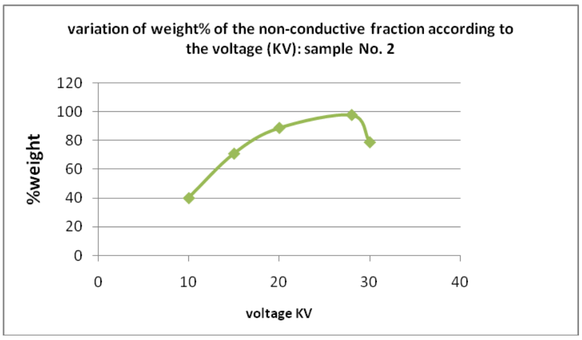


Figure 11. Curve of variation of the weight% of the non-conductive portion in function of the voltage (kV): case of the average sample AM2.

The best yield weight is obtained with 28 kilovolts. If the voltage exceed this threshold the result becomes less efficient.

Indeed, by applying a voltage higher than 28 kilovolts a double failure is present: firstly the manifestation of a very intense electrical discharge and secondly the substantial decrease of the weight of non-conductive fraction yield (Example AM1 sample the% weight decreases from 99 to 82%). The voltage of 28 kilovolts is the ideal voltage for efficient separation while maintaining the other parameters constantThe results of chemical analyses of the non-conductive fraction are represented in table 6.

Table 6 : Results of chemical analyses of the final product after attrition treatment, gravity separation, wet high intensity magnetic separation and electrostatic separation.

Sample	SiO_2 %	Al_2O_3 %	CaO %	Fe_2O_3 %	K_2O %	MgO %	Na_2O %	TiO_2 %	Cr (ppm)	Cu (ppm)
Sample 1	99.99	0.008	0.005	0.0009	0.009	0.002	0.003	0.001	nd	nd
Sample 2	99.97	0.01	0.009	0.0010	0.009	0.004	0.003	0.002	nd	nd
Sample 3	99.94	0.03	0.011	0.0013	0.01	0.003	0.004	0.004	nd	nd

nd: not detected

It is shown that the depletion of iron oxide (0.0009% Fe2O3) and titanium oxide (0.001 %TiO2) in the non conductive fractions (Table 6) was successfully conducted.

This proves that the adopted treatment approach decrease the potential of contamination for the final product of quartz sand. Therefore, the obtained product could be used in high technology industries such as the manufacture of silicon for photovoltaic cells manufacture, optical fibers and electronic chip.

This type of testing has also been undertaken with only attrition of sands. The beneficiation of the sand is less effective.

These induce that gravity and wet magnetic separation and electrostatic separation, were needed to make an efficient recovery process.

The processing steps are illustrated in summarized flow-sheet.

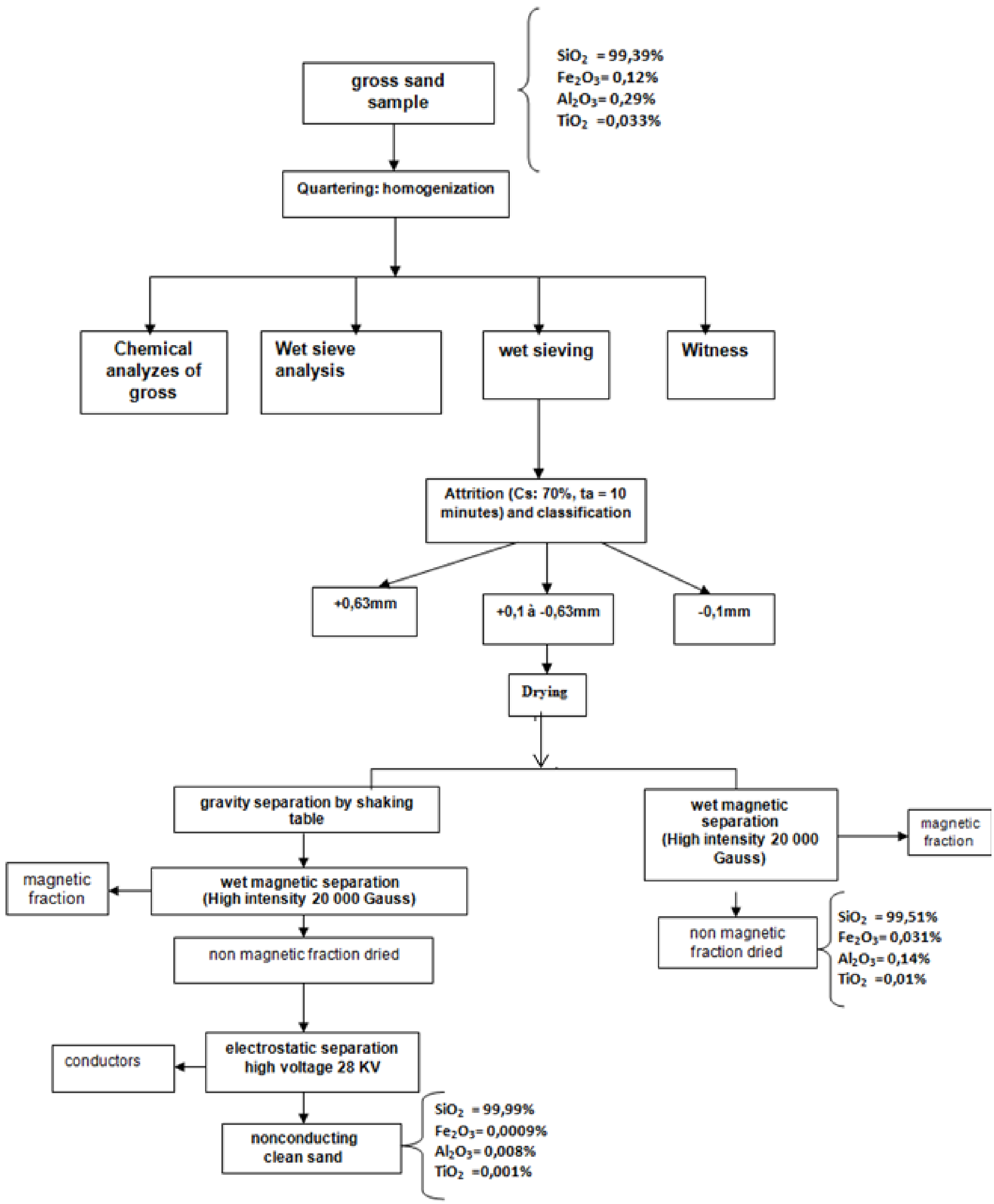


Figure 13: Flowsheet of the two presented schemes

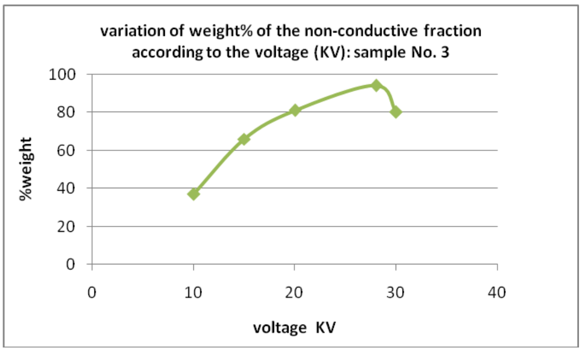


Figure 4 Curve of variation of the weight% of the non-conductive portion in function of the voltage (kV): case of the average sample Am3

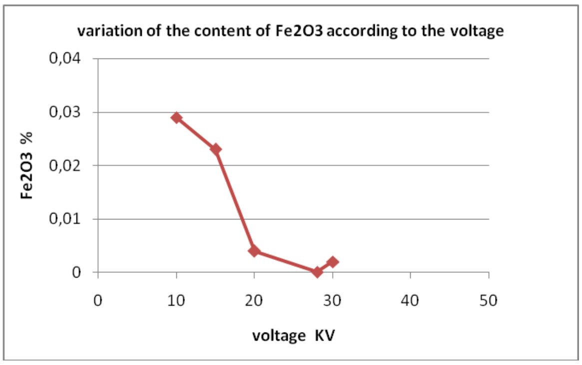


Figure 5. Variation curve of the Fe2O3 content in function of the voltage (kV) If the average sample AM3.

Conclusion

Mineralogical and chemical studies carried out on silica sand samples from Ain Bou Morra area shows that the main impurities are iron, titanium and feldspar minerals. Most of the impurities are distributed in the finer fraction (flat glass, optical glass, glass white, half white glass, glass wool and glass brick) and also for the chemical industry (silicate manufacturing soda).

While under the second scheme, prepared sands can be used even for the manufacture of crystal glass as raw material for silicon production which is the main element used for the manufacture of photovoltaic solar cells and electronic chips.

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References

- Added M., 2005. Impact de la qualité des granulats sur les caractéristiques physico-mécaniques des mortiers et des bétons. Thèse Doc. Univ. Tunis El Manar. Faculté des Sciences de Tunis.175p.
- Aloui T., 2010. Etude sédimentologique et intérêt économique des sables d'âge barrémien (formation Sidi Aich) Tunisie Centro-méridionale. Thèse Doc. Univ. Tunis II, Tunisie. 287p.
- Ben Fradj M., 2010.Etude minéralogique, chimique et minéralurgique des sables de Menzel Mhiri et de Ain Bou Morra. Mémoire de Mastère. Univ. Tunis El Manar. Faculté des Sciences de Tunis. 131p.
- Ben Haj Ali, M., Jedoui, Y., Ben Salem, H., Memmi, L., 1985.Carte géologique de la Tunisie : 1/500 000. Office National des Mines, Service Géologique.
- Gaied M.S., 1991. Géologie des matériaux utiles de la région d'El Gnater (Tunisie Centrale). Mémoire de DEA. Univ. Tunis El Manar. Faculté des Sciences de Tunis. 118p,
- Gaied M. E, Gallala W., 2011. Beneficiation of feldspar ore for application in the ceramic industry: Influence of composition on the physical characteristics. Arabian Journal of Chemistry, V.8, 2, p186–190.
- Gallala, W. (2010). Les sables quartzo-feldspathiques de la Tunisie centro-méridionale: sédimentologie, minéralogie, minéralurgie et applications industrielles, PhD Thesis, Faculty of Sciences Sfax, Tunisia.
- Gallala W, Gaied M. E., Montacer M., 2009. Concentration of Potassium Feldspar from Low-grade Sidi Aïch Sand in Tunisia for Industrial Applications. Silicates industriels, no 5-6, p. 125-130.
- Griffits J., 1987. Silica. Is the choice crystal clear. Industrial Minerals, n° 235. Pp 25-43.

- El Maaoui M., 1993. Chimie pratique du verre. Rapport, CTMCCV.
- Harben, Peter W., KuŽvart, M., 1997. Industrial minerals: a global geology. Metal Bulletin.
- Jamoussi F., 1991. Etude géologique et géotechnique des substances minérales utiles de la région de Gafsa. Thèse de spécialité. Faculté des Sciences de Tunis. 298p.
- Jouirou M., 1981. Etude géologique et géochimique des sédiments de la région d'El Kef (NW de la Tunisie). Thèse Doc. Univ. de Bordeaux.146p.
- Louhaichi M.L., 1981. Etude géologique et géotechnique de la partie nord-occidentale du gouvernorat de Kairouan (Tunisie) application à la recherche et à la cartographie des matériaux utiles. Thèse Doc. Univ. Franche-Comté. Faculté des sciences et des techniques. 146p.
- Ounis M.S., 2004. Contribution a l'étude du sable Oligocène de Oueslatia application aux domaines de l'industrie. Diplôme de mastère en géologie, Faculté des sciences de Tunis. 67p.
- Trabelsi, H., 1989. Les matériaux utiles de la région de Feriana (Tunisie centrale) (cadre géologique et potentialités). Thèse de doctorat, Nice.

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