Silica Sand Potential of the Ebenebe Sandstone, Anambra State, Nigeria

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ABSTRACT

The Ebenebe Sandstone is a component of the Paleocene Imo Formation in south-eastern Nigeria. The deposit in Anambra State was subjected to textural and chemical analyses to establish the silica sand potential, and suitability for various industrial applications. The research is a contribution to government's effort toward solid mineral exploration and exploitation to support industrialization of the State. The research strategy involved (i) detailed sampling of outcrops of the Ebenebe Sandstone deposit in Anambra State, (ii) grain size analysis to evaluate the textural parameters critical for various industrial applications, and (iii) x-ray fluorescence analysis to establish the chemical composition and industrial quality of the sandstone. Evidence from grain size analysis shows that the sandstone is medium to coarse-grained, moderately well sorted, positively-negatively skewed, and thus texturally mature and adequate for the production of various glass wares. X-ray fluorescence studies revealed that the Ebenebe Sandstone is a quartz arenite containing Silica (90.5%), Aluminium oxide (5.30%) and Titanium oxide (0.24%), among others. The observed percentage of silica is far below the British Standards specification of 99.99% for the manufacture of solar panel and various glass wares. On the other hand the observed percentages for the oxides of Aluminium, and Titanium are far above the 1.5 % and 0.1% minimum concentration required in the glass industry. Appropriate beneficiation processes (such as magnetic separation and acid leaching) are therefore required to upgrade the silica concentration of the Ebenebe Sandstone to the required 99.99%, to meet the specification for use as raw material for the manufacture of solar panel, and various kinds of glass wares. Industrial exploitation of the sand deposit by government is thus strongly recommended to sustain a glass industry and boost the economy of Anambra State

Keywords: Ebenebe Sandstone, silica sand, textural maturity, quartz arenite, beneficiation, industrial potential.

INTRODUCTION

Background to Study

Anambra State is endowed with extensive sandstone deposits including (i) the Ebenebe Sandstone (a component of the Paleocene Imo Formation), (ii) the Nanka Sand, a component of the Eocene Ameki Formation (Nwajide, 1979)[1], (iii) the sandy component of the Oligocene Ogwashi-Asaba Formation (Uduezue, et al. 2021)[2], and the alluvial sands of the River Niger (Echefu, 2019)[3]. Previous researches have evaluated the suitability of Eocene-Oligocene sand deposits in the State for the production of various glass wares, and for commercial production of solar panels (Mgbenu, 2018[4]; and Echefu, 2019[3]). These researches established that beneficiation would be required to upgrade the sand deposits to meet the standard requirements for the production of various glass wares, and for commercial production of solar panels. The Ebenebe Sandstone crops out on the eastern edge of Anambra State, in south-eastern Nigeria where the sand body is topographically expressed as a ridge. The ridge extends from Ebenebe town and trends in a slightly N-S direction, passing through Ugwuoba, Isiagu, Ufuma, Ajali and Umunze and beyond (Fig. 1.1).

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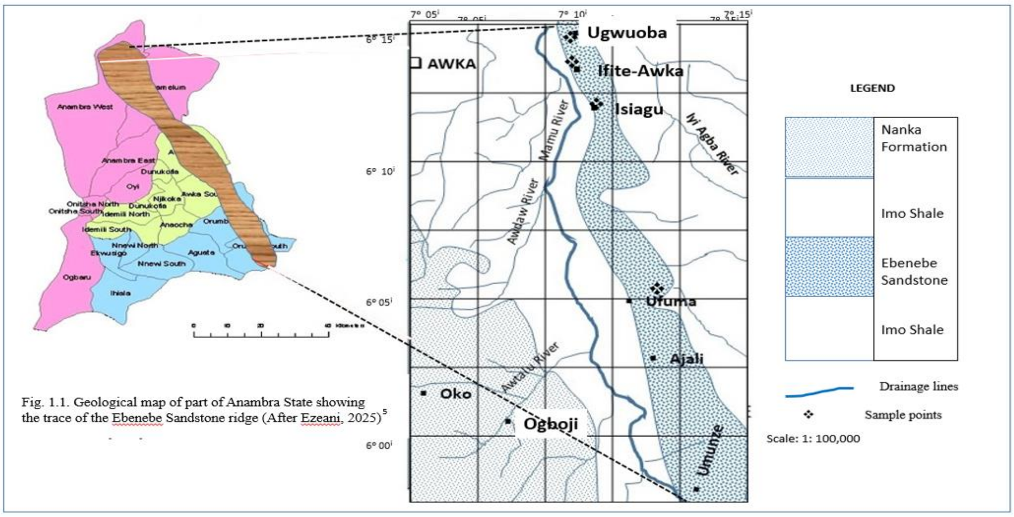

Fig. 1.1. Geological map of part of Anambra State showing the trace of the Ebenebe Sandstone ridge (After Ezeani, 2025)[5]

The objective of the present study is to evaluate the textural, and chemical parameters of the Ebenebe Sandstone to establish the suitability of the deposit for various industrial applications.

LITERATURE REVIEW

The term sand has several definitions but in the present context, refers to an unconsolidated, or moderately consolidated sedimentary deposit consisting essentially of fine to coarse grained siliceous clastics resulting from the disintegration of pre-existing rock (Gary et al, 1972)[6]. It is referred to as silica sand when it contains up to 90% of grains of quartz (silicon dioxide, or SiO_2). Quartz, the most common silica crystal and the second most common mineral on the earth's surface, is found in almost every type of rock; igneous, metamorphic and sedimentary (Pettijohn et al., 1975[7]; Ketner, 1973[8]). While quartz deposits are abundant, and quartz is present in some form in nearly all mining operations, high purity and commercially viable deposits occur less frequently. The composition of silica sand is highly variable, depending on the local rock sources and conditions.

According to Pettijohn et al., (1973)[9] pure silica sand may be produced from sandstones, quartzite and loosely cemented or unconsolidated sand deposits. High grade silica is normally found in unconsolidated deposits below thin layers of overburden rocks. It is also found as "veins" of quartz within other rocks and these veins can be many meters thick. The sands after mining go through a beneficiation process to increase the silica content and reduce the impurities that may include oxides of potassium and sodium which are usually present at 1.0 ppm concentration and aluminium impurities which are present at about 12 ppm concentration (Pettijohn et al., 1973)[9].

Table 1.1. Silica sand Grade for Solar Panel and Container Glass (Platias *et al.*, 2014)[10]

Parameter	Specifications	
	Solar Panel	Container Glass
Particle Size	109-700 microns	109-700 microns
Mesh Range	24-140 mesh	24-140 mesh
Silica (SiO_2)	> 99.5%	> 98.5%
Iron (Fe2O_3)	< 0.01% (100 ppm)	< 0.04% (400 ppm)
Titanium (TiO_2)	< 0.04% (400 ppm)	< 0.1% (1000 ppm)
Aluminium (Al2O_3)	< 0.10% (1000 ppm)	< 0.50% (5000 ppm)

Table 1.1 shows the commercial silica sand specifications for solar panel and container glass. Whereas the particle size and mesh range for both solar panel and the container glass are the same, the Silica (SiO_2), Iron

(Fe_2O_3), Titanium (TiO_2) and Aluminium (Al_2O_3) percentages for the two products are different. Highest silica purity is required for the manufacture of solar panels (Platias et al., 2014)[10].

METHODS OF STUDY

Mean grain size, grain shape and chemical composition largely determine the industrial potential of a sand deposit (Platias et al., 2014)[10]. The study strategy thus focused on grain size analysis and chemical analysis. In the field, bed-to-bed sampling was adopted to assure true representation. The analytical strategy focused on (i) the conventional sieve analysis to determine the grain size and suitability of the grain size distribution, and (ii) X-ray fluorescence analysis to establish chemical composition of the samples.

Grain size Analysis

Twelve representative sand samples were taken from the Ebenebe Sandstone ridge at Ifite Awka, Isiagu and Enugu Abor-Ufuma-Ufuma (Fig. 1.1), and subjected to mechanical sieve analysis. The samples were generally poorly cemented, and thus presented no problems during disaggregation. The samples were first viewed under the binocular microscope to determine the shape of the grains**.** Fifty (50) grams of each disaggregated sample was sieved for 15 minutes on a Ro-Tap Sieve Shaker using a set of US Standard Sieves at a 1/4 phi sieve interval following the method of Folk (1980)[11]. The raw grain size data obtained from the sieve analysis of each of the four samples collected from Ifite-Awka, Isiagu and Enugu Abor-Ufuma-Ufuma, are presented in Tables 2.1-2.3. To give an immediate impression of the distribution the grain-size data were presented as cumulative frequency plots (Figs. 2.1a-c) following the method of Visher (1969)[12]. From the cumulative frequency plots the critical percentiles (Q5, Q16, Q25, Q50, Q75, Q84 and Q95) were extrapolated (Table 2.4) and used to compute the statistical parameters: mean size (mz), sorting coefficient (σ_I), skewness (sk_I), and kurtosis (k_G), using the Folk and Ward's (1957)[13] formulae as defined in Table 2.5.

Table 2.1. The raw sieve data for the Ebenebe at Ifite-Awka.

Phi intervals	Ifite Awka -1		Ifite Awka -2		Ifite Awka -3		Ifite Awka -4	
	-Wt%	Cum wt%	-Wt%	Cum wt%	-Wt%	Cum wt%	-Wt%	Cum wt%
-1.5- -1.0	0.58	0.58	0.22	0.22	3.98	3.98	8.40	8.40
-1.0- -0.5	0.58	1.16	0.22	0.44	4.48	8.46	12.20	20.60
-0.5-0.0	5.88	7.04	0.90	1.34	22.88	31.34	13.60	34.20
0.0-0.5	25.86	32.90	2.06	3.40	10.78	42.12	11.20	45.40
0.5-1.0	37.92	70.82	8.70	12.10	17.42	59.54	17.00	62.40
1.0-1.5	18.02	88.84	34.12	46.22	15.76	75.30	18.40	80.80
1.5-2.0	3.32	92.16	50.40	96.62	13.44	88.74	11.40	92.20
2.0-2.5	1.96	94.12	0.16	96.78	5.80	94.54	3.80	96.00
2.5-3.0	1.96	96.08	2.30	99.08	4.64	99.18	2.80	98.80
3.0-3.5	1.96	98.08	0.46	99.54	0.82	100	0.60	99.40
3.5-4.0	1.96	100	0.46	100	- -	100		100
Total	100.00		100.00		100.00		100.00	

Table 2.2. The raw sieve data for the Ebenebe Sandstone at Isiagu.

Phi intervals	Isiagu -1		Isiagu -2		Isiagu -3		Isiagu -4	
	-Wt%	Cum wt%	-Wt%	Cum wt%	-Wt%	Cum wt%	-Wt%	Cum wt%
-1.5- -1.0	1.34	1.34	0.70	0.70	1.72	1.72	0.32	0.32
-1.0- -0.5	1.86	3.20	1.58	2.28	5.72	7.44	0.92	1.24
-0.5-0.0	6.02	9.22	8.90	11.18	21.88	29.32	3.38	4.62
0.0-0.5	21.02	30.24	20.20	31.38	34.20	63.52	11.48	16.10
0.5-1.0	36.20	66.44	34.08	65.46	18.82	82.34	19.74	35.84
1.0-1.5	22.96	89.40	20.68	86.14	8.44	90.78	36.92	72.76
1.5-2.0	7.54	96.94	5.76	91.90	3.58	94.36	20.72	93.48
2.0-2.5	2.42	99.36	4.96	96.86	2.24	96.60	5.72	99.20
2.5-3.0	0.38	99.74	2.16	99.02	2.00	98.60	0.54	99.74
3.0-3.5	0.10	99.84	0.56	99.58	1.18	99.78	0.16	99.90
3.5-4.0	0.16	0100	0.42	100	0.22	100	0.10	100
Total								

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Table 2.3. The raw sieve data for the Ebenebe Sandstone at Enuguabor -Ufuma

Phi intervals	Enuguabor -1		Enuguabor -2		Enuguabor -3		Enuguabor -4	
	-Wt%	Cum wt%	-Wt%	Cum wt%	-Wt%	Cum wt%	-Wt%	Cum wt%
-1.0- -0.5	0.62	0.62	1.10	1.10	2.12	2.12	1.30	1.30
-0.5-0.0	1.12	1.74	1.52	2.62	4.54	6.66	1.70	3.00
0.0-0.5	3.06	3.98	3.54	6.16	6.26	12.92	5.50	8.50
0.5-1.0	15.48	19.46	21.82	27.98	19.92	32.84	23.5	32.00
1.0-1.5	34.42	54.17	37.28	65.26	32.38	65.22	32.00	64.00
1.5-2.0	32.38	87.08	12.72	77.98	28.04	93.26	15.40	79.40
2.0-2.5	5.04	92.12	12.12	90.10	3.12	96.38	9.70	89.10
2.5-3.0	4.82	96.94	6.26	96.36	2.42	98.80	7.50	96.60
3.0-3.5	3.06	100	3.64	100.00	1.22	100.00	3.40	100
Total	100.00		100.00		100.00		100.00	

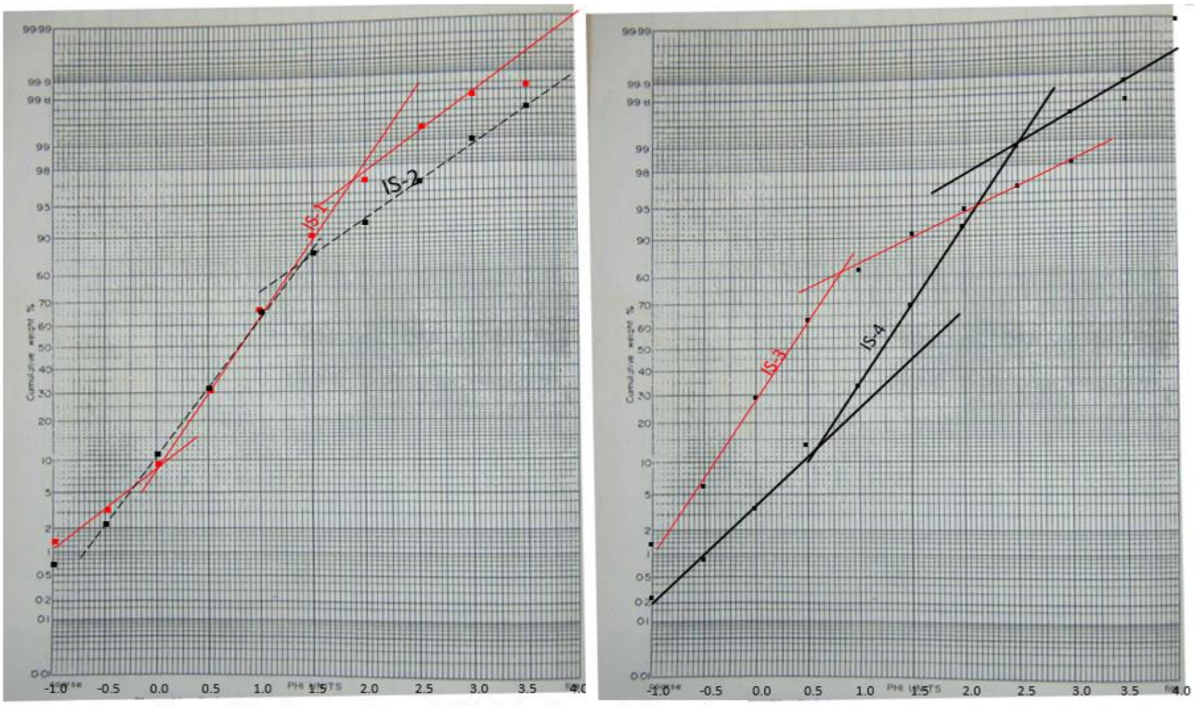

Fig. 2.1 (b) . Cumulative frequency (Log-probability) plots for samples from Isiagu

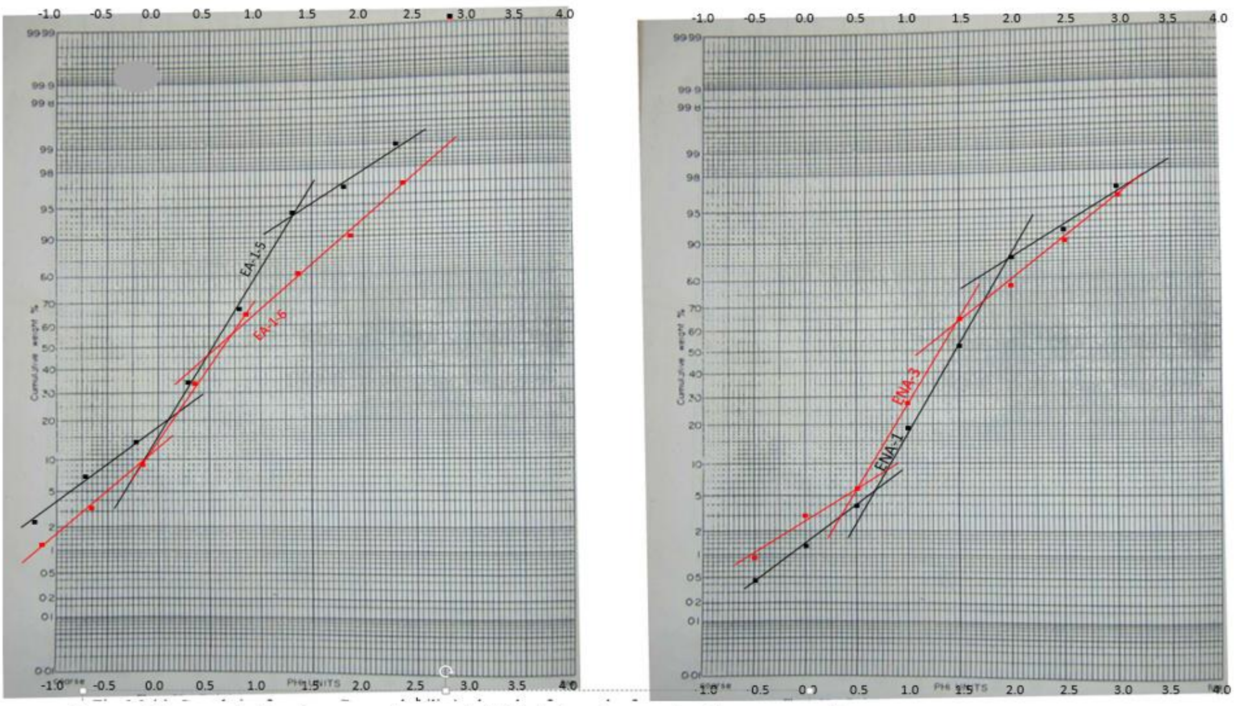

Fig. 2.1 (c)).. Cumulative frequency (Log-probability) plots for samples from Enugu Abor

Table 2.4. Critical percentiles extrapolated from the cumulative frequency plots

Percentiles	Ifite Awka -1	Ifite Awka -2	Ifite Awka -3	Ifite Awka -4
	Phi	Phi	Phi	Phi
Q5	-0.15	0.90	-0.90	0.00
Q16	0.20	1.20	-0.25	-0.75
Q25	0.35	1.25	0.00	-0.25
Q50	0.75	1.45	0.60	0.50
Q75	1.1	1.65	1.50	1.35
Q84	1.25	1.75	1.75	1.65
Q95	2.75	1.95	2.5	2.30
Percentiles	Isiagu-1	Isiagu-2	Isiagu-3	Isiagu-4
Q5	-0.30	-O.25	-0.6	0.10
Q16	0.20	0.15	-0.25	0.65
Q25	0.40	0.35	-0.05	0.85
Q50	0.75	0.80	0.30	1.20
Q75	1.15	1.25	0.70	1.60
Q84	1.30	1.40	0.95	1.75
Q95	1.70	2.25	2.10	2.4
Percentiles	Enuguabor-1	Enuguabor -3	Enuguabor -5	Enuguabor -6
Q5	0.65	0.40	-0.10	0.20
Q16	1.00	0.80	0.65	0.70
Q25	1.10	0.95	0.90	0.90
Q50	1.45	1.30	1.25	1.30
Q75	1.80	1.85	1.60	1.90
Q84	1.95	2.15	1.75	2.20
Q95	2.70	2.85	2.25	2.85

Table 2.5. Statistical parameters as described by Folk and Ward (1957) [12]

Parameter	Formulae	Verbal Terms
M_Z	$\frac{\phi16 + \phi50 + \phi84}{3}$	$M_Z =$ 0-1: coarse sand
		1-2: medium sand
		2-3: fine sand
σ_I	$\frac{\phi84 - \phi16}{4} + \frac{\phi95 - \phi5}{6.6}$	σ_I < 0.35: very well sorted
		0.35- 0.50: well sorted
		0.50- 0.8: moderately well sorted
		0.8-1.4:Moderately sorted
		1.4- 2.0 poorly sorted
		2-2.6: Very poorly sorted
		>2.6: extremely poorly sorted
Sk_i	$\frac{\phi16 + \phi84 - 2(\phi50)}{2(\phi84 - \phi16)} + \frac{\phi5 + \phi95 - 2(\phi50)}{2(\phi95 - \phi5)}$	Sk_i > +1.0- +0.3: very positively skewed
		0.3-0 .1: positively skewed
		0.1- -0.1: symmetrical
		-0.1- -0.3:negatively skewed
		-0.3- -1.0: very negatively skewed
K_G	$\frac{\phi95 - \phi5}{2.44(\phi75 - \phi25)}$	K_G < 0.67: very platikurtic
		0.67- 0.90 platykurtic
		0.90-1.11: mesokurtic
		1.11-1.50: leptokurtic
		1.50-3.0:very leptokurtic
		>3.0: extremely leptokurtic

X-Ray Fluorescence Method

Ten (10) representative samples of the Ebenebe Sandstone were taken from Ugwuoba, Ifite-Awka, Isiagu and Enugu Abor-Ufuma (Fig. 1.1), The X-ray fluorescence method was used to determine the percentage concentrations of the metal oxide including SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, Na_2O, CaO, and K_2O, following

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the method of Fairchild et al., (1988)[14]. The samples were first crushed using the Tema vibrating mill, to reduce the grains to less than 63 microns. The agate mortar in the ring mill crushed the samples before they were sieved.

About 5.0g of dry rock sample powder was weighed in a silica crucible and then ignited in the furnace at 1000^0c for 2 to 3 hours for the calcinations of impurities in the rock powder. The samples were then removed from the furnace and allowed to cool to room temperature in desiccators. Each ignited rock powder was then weighed again to determine the weight of the calcinated impurities such as H_2O, H_2O^+ and CO_2.

One gram (1.0g) of the stored ignited rock powder was weighed and exactly 5 times of flux (X-ray Flux-Type 66:34% (66.0% Lithium Tetraborate: 34% Lithium metaborate) was added to lower the vitrification temperature of the rock powder. The weighed mixture was mixed properly in a platform dish and ignited in the pre-set furnace (Eggon 2 Automatic fuse bead maker) at 1500^0c for 10 minutes to form glass bead. Each glass bead was labelled and slotted into the computerized XRF (Epilson 5 Panalytical model) for major elemental analysis.

RESULTS AND DISCUSSION

Results and Interpretation of Textural Parameters

The statistical grain size parameters computed for the Ebenebe sandstone samples are presented in Table 3.1.

Table 3.1. Textural parameters of the Ebenebe Sandstone samples from the study area

Location	Graphic measures							
Ifite Awka	Mz	Verbal term	σ_I	Verbal term	Ski	Verbal term	K_G	Verbal term
04	0.47	Coarse	0.57	Moderately well sorted	0.26	Positively skewed	0.59	Very platikurtic
03	0.70	Coarse	0.62	Moderately well sorted	0.43	Very positively skewed	0.93	Mesokurtic
02	1.47	Medium	1.17	Moderately sorted	0.07	Symmetrical	1.07	Mesokurtic
01	0.73	Coarse	0.76	Moderately well sorted	0.17	Positively skewed	1.07	Mesokurtic
Isiagu								
04	1.20	Medium	0.98	Moderately sorted	0.02	Symmetrical	1.26	Leptokurtic
03	0.33	Coarse	0.40	Well sorted	0.21	Positively skewed	1.47	Leptokurtic
02	0.78	Coarse	0.69	Moderately well sorted	0.06	Symmetrical	1.14	Leptokurtic
01	0.75	Coarse	0.59	Moderately well sorted	-0.02	Symmetrical	1.09	Mesokurtic
Enuguabor-Ufuma								
06	1.40	Medium	1.19	Moderately sorted	0.18	Positively skewed	0.21	Very platikurtic
05	1.22	Medium	0.93	Moderately sorted	-3.4	Negatively skewed	1.37	Leptokurtic
03	1.42	Medium	1.23	Moderately sorted	0.48	Very positively skewed	1.11	Leptokurtic
01	1.47	Medium	1.25	Moderately sorted	0.14	Positively skewed	1.20	Leptokurtic

The raw sieve data (Tables 2.1-2.3) consistently show that the samples are generally concentrated within the medium to coarse (0.0 ph-2.0 phi) size range. The computed textural parameters (Table 3.1) show that the Ebenebe Sandstone is essentially medium to coarse-grained, moderately well sorted, positively-negatively skewed, and thus generally adequate for glass manufacture.

Textural Maturity

Textural maturity is a measure of the degree to which sand is free of interstitial clay (matrix) and to which it is well sorted and well rounded (Folk, 1980)[11]. The degree of the textural maturity of sand determines its suitability as raw material in the glass industry (Platias, 2014)[10]. To assess the textural maturity of the samples, the method described by Pettijohn (1975)[7] was followed. Roundness of the grains as determined using the Powers Roundness image chart as given by Pettijohn (1975)[7], is angular to sub-rounded (Fig. 3.1).

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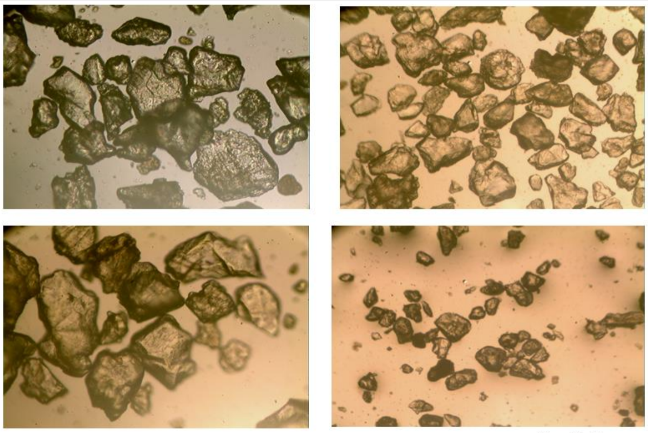

Mag = X 40

Fig. 3.1. Photomicrographs of disaggregated samples of the Ebenebe Sandstone showing angular to sub-rounded grains

According to Pettijohn (1975)[7], immature sand contains over 5% clay matrix, and the grains are generally angular and poorly sorted. A sub mature sand on the other hand contains less than 5% matrix, is poorly sorted, and generally not well rounded, while mature sand contains little or no clay, is well sorted but not well rounded. Super mature sand contains no clay matrix, the grains are well sorted and well-rounded. Table 3.2 summarizes the textural maturity parameters of the Ebenebe Sandstone.

Table 3.2. Summary of the textural maturity parameters of the Ebenebe Sandstone

	Ifite-Awka	Isiagu	Enuguabor	Average
SiO_2	89.16	91.70	90.45	90.44
Clay %	2.82% (Mature)	0.22% (Mature)	0.75% (Mature)	1.26% (Mature)
Sorting	0.78 Moderately well sorted	0.66 Moderately well sorted	1,15 Moderately sorted	0.86 Moderately sorted

Tables 3.1 and 3.2 show that the Ebenebe Sandstone samples are on the average moderately well sorted, and contain very little clay (0.2% to less than 3% clay). Based on these parameters, the samples are classified as being texturally mature and therefore have potential to yield silica sand that could be utilized as an industrial raw material for the production of glass wares.

Results and Interpretation of X-Ray Fluorescence Data

Composition

The chemical composition of the Ebenebe Sandstone as determined by x-ray fluorescence analysis is presented in Table 3.3. The result reveals that quartz (SiO_2) has the highest concentration that ranges from about 89% to approximately 92.5%, with an average of 90.57%. Next in abundance is Alumina Al_2O_3, (4.15%-6.74%), followed by Iron oxide, Fe_2O_3 (2.44%-3.80%). The result also reveals that the percentage of total alkali-earth oxides is low. This indicates that silica is the dominant cement in the Ebenebe Sandstone.

Table 3.3.: Result of X-Ray Fluorescence Analysis showing percentages of the raw oxides

locality	Ugwuoba		Ifite-Awka		Isiagu			Enuguabor			AVERAGE
OXIDES %	1	2	3	4	5	6	7	8	9	10	
SiO_2	90.63	90.34	88.93	89.39	91.29	92.49	91.29	91.79	89.29	90.29	90.57
TiO_2	0.33	0.25	0.24	0.23	0.15	0.32	0.23	0.18	0.24	0.20	0.24
Al_2O_3	6.52	6.74	6.56	5.10	4.90	4.15	4.50	4.30	5.0	5.2	5.30
Fe_2O_3	2.44	2.59	3.80	3.45	3.35	2.62	3.10	3.22	3.70	3.80	3.21
MgO	0.01	0.01	0.10	0.10	0.05	0.04	0.01	0.01	0.12	0.15	0.06
K_2O	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Na_2O	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CaO	0.05	0.05	0.65	1.71	0.25	0.36	0.76	0.49	1.64	0.34	0.63

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Classification

Akinyemi et al (2014)[15] used the log ratios of chemical oxides to classify sandstones. The range of values for different log ratios and their descriptive terms are summarized in Table 3.4. This scheme was adopted in this study to classify the Ebenebe Sandstone.

Table 3.4: Chemical classification sandstone using log ratios (After Akinyemi, 2014)

S/N	Log of ratios of oxides	Types of sandstone
1	Log $(SiO_2/Al_2O_3) > 1.5$	Arenite
2	Log $(SiO_2/Al_2O_3) > 1$ and Log $(K_2O/Na_2O) < 0$	Greywacke
3	Log $(SiO_2/Al_2O_3) > 1.5$ and Log $(K_2O/Na_2O) > 0$ and log $(Fe_2O_3 + MgO)/(Na_2O + K_2O)$	Arkose
4	Log $(SiO_2/Al_2O_3) > 1.5$ and either Log $(K_2O/Na_2O) < 0$ and log $(Fe_2O_3 + MgO)/Na_2O > 0$	Lithic arenite (including sub-greywackes and protoquartzites

Table 3.5 shows that the log of the silica: alumina ratio computed for the Ebenebe Sandstone ranges from 1.56 to 1.64, with an average value of 1.59, while log of K_2O/Na_2O is consistently zero. Based on the scheme of Akinyemi et al (2014)[15], and the dominance of silica cement in the samples, the Ebenebe Sandstone is classified as silica-cemented quartz arenites.

Table 3.5. Computed logs of the ratios of oxides

Sample Nos	Log (SiO_2/Al_2O_3)	Log $(MgO + Fe_2O_3)$	Log (Fe_2O_3/K_2O)	Log $((Fe_2O_3+MgO)/(Na_2O+K_2O))$	Log (K_2O/Na_2O)	Log$((Fe_2O_3+MgO)/Na_2O)$
1	1.60	0.39	2.387389	2.09	0.0	2.389166
2	1.57	0.41497	2.41329	2.11394	0.0	2.41497
3	1.56	0.591064	2.579783	2.290034	0.0	2.414973
4	1.59	0.550228	2.537819	2.249798	0.0	2.550228
5	1.64	0.531478	2.525044	2.230448	0.0	2.531478
6	1.64	0.42488	2.418301	2.123851	0.0	2.424881
7	1.57	0.492760	2.491361	2.131939	0.0	2.492760
8	1.61	0.509202	2.507855	2.208172	0.0	2.509202
9	1.57	0.582063	2.568201	2.281033	0.0	2.582063
10	1.63	0.596597	2.579783	2.582063	0.0	2.596970
Average	1.59	0.51	2.579783	2.20	0.0	2.50

Herron (1988)[16] used the plot of log (SiO_2/Al_2O_3) against log (Fe_2O_3/K_2O) to classify sandstones and shales. This strategy was also employed in the present study to classify the Ebenebe Sandstone. The plot (Fig. 3.2) shows that 100% of the samples plotted in the quartz arenite field.

Chemical Maturity: Pettijohn et al. (1975)[7] considered percentage of silica (quartz) in sandstone as an index of mineralogical /chemical maturity, and sandstones that contain more than 90% silica are chemically mature. Such sands are the silica sands that provide the raw material for the glass industry.

Table 3.3 shows that the Ebenebe Sandstone samples all contain 89% -92% silica (average 90.57%). Based on this parameter, the sand is classified as chemically mature quartz arenite and therefore have potential to yield silica sand that could be utilized as an industrial raw material for production of glass wares.

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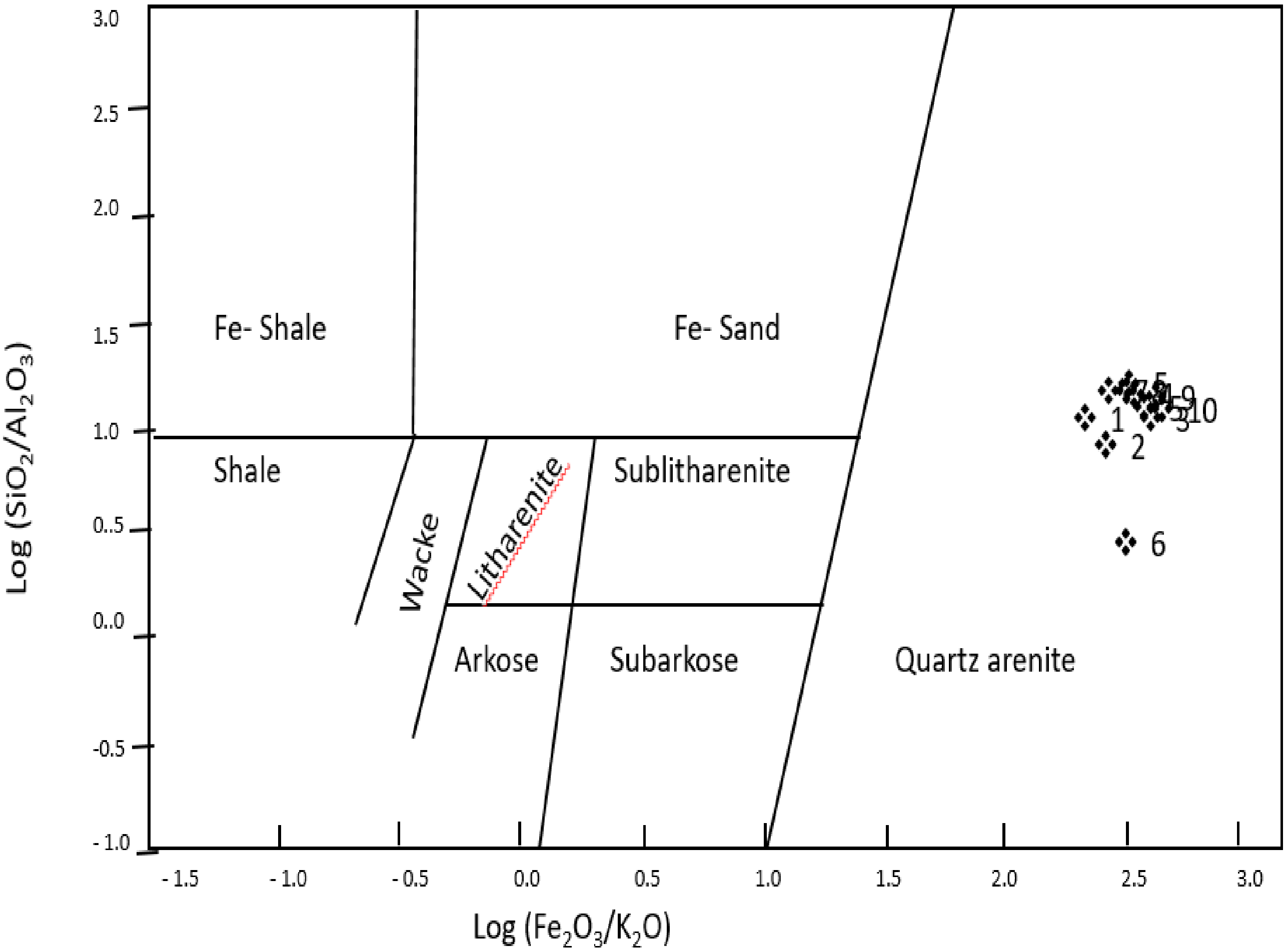

Fig.:3.2. Chemical classification of the Ebenebe Sandstone using binary plot of log (SiO_2/Al_2O_3) against log (Fe_2O_3/K_2O) (Herron, 1988)[24].

DISCUSSION

This study has highlighted the textural and chemical parameters of the Ebenebe Sandstone in Anambra State Nigeria and provided basis to evaluate the silica sand potential and suitability as raw material for the glass industry and for the manufacture of solar panels.

Suitability for Glass Industry

Results of the grain size analysis conducted in this study have shown that the Ebenebe Sandstone is generally medium to coarse grained, moderately well sorted and composed of angular to sub-rounded, quartz grains. As stated by McLaws (1971)[17], for silica sand to be suitable for the glass industry, most of the grain size must fall within 0.5mm to 0.09mm (i.e., coarse to medium sand). This is because grain size homogeneity influences the consistency of melting, and glass makers insist on a narrow grain size range to achieve the desired result. Angular to sub-rounded grains melt more quickly and evenly than well rounded grains (McLaws, 1971)[17]. According to McLaws (1971)[17] the melting quality of glass sand is controlled by the chemical composition as reflected in the amount of silica (SiO_2). A minimum silica percentage composition of 95% is therefore set as the thresh hold for green glass, sheet glass, amber glass and flint glass, while a higher value of 99.8% SiO_2 is required for optical glass.

The presence of alumina and titanium oxides raises the melting temperature of glass and reduces the transparency (McLaws, 1971)17. The allowable iron, alumina and titanium oxides concentration for the common varieties of glass wares are shown in Table 4.1 below. A minimum of 1.5 % and 0.1% concentration for alumina and titanium respectively are recommended.

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When the average silica, iron, alumina and titanium oxides concentration of the Ebenebe Sandstone (90.57 %) are compared with the British glass requirements, it can be seen that the Ebenebe Sandstone is texturally suitable as raw material for manufacture of various glass wares. However, the sandstone does not have optimum silica concentration for the manufacture of the various types of glass wares.

Table 4.1. The allowable iron concentration for the common varieties of glass (McLaws, 1971)[15]

Variety of glass products	Fe_2O_3 concentration	Al_2O_3	TiO_2
Optical glass	0.013 %	1.50	0.10
Float glass	0.1 % ± 0.005		
Coloured container glass	0.25 % ± 0.03		

Solar Technology

The British Standards (BS2975, 1988) has set 99.99% silica as the requirement for sand to be used as raw material for the manufacture of solar panel. Table 4.2 compares the result of chemical analysis of the Ebenebe Sandstone with the British Standards ((BS2975, 1988). The percentage of silica in the samples averages 90.57%. This value is far below the 99.99% requirement set for the manufacture of solar panel. Similarly, the percentages for the other oxides are all beyond the bench mark for the various applications, except MgO% (Table 4.2) which is within permissible limits for all applications.

Table 4.2. Critical percentage limits for essential chemical oxides required for various industrial applications

Grades (BS2975; 1988)[15]	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO
Solar	99.99	0.1 % ± 0.005	<0.3	<0.1	<0.1
Colourless	>98.8	<0.03	<0.1	<0.5	<0.5
Coloured glass	>97.0	0.25 % ± 0.03	<0.1	<0.5	<0.5
Borosilicate	>99.6	<0.01	<0.2	<0.5	<0.5
Clear flat glass	>99.0	0.1 % ± 0.005	<0.5	<0.5	<0.5
Optical	>99.7	<0.013	<0.2	<0.1	<0.1
Tableware/crystal glass	>99.6	<0.01	<0.2	<0.2	<0.2
Insulating fibre	>94.5	0.3 % ± 0.03	<3.0	<0.5	<0.5
Ebenebe Sandstone	90.57	3.21	5.30	0.06[xx]	0.63

Based on the above results we conclude that the Ebenebe Sandstone in its natural form is not suitable for the manufacture of solar panels. If however, the percentages of Fe_2O_3 and Al_2O_3 are greatly reduced through beneficiation processes, silica percentage can be improved enough to make the resulting product suitable for the manufacture of solar panels.

Foundry industry

Kogel (2006)[18] has demonstrated that silica sand can be utilized in the making of molds and cores for metal casting, provided the sand is sufficiently available at low cost and possess appropriate physical and chemical parameters. As outlined by Brown (2000)[19], the permeability and binder requirement of molding sand, as well as the smoothness of the metal are controlled by grain size. Kuzvart (1984)[20] and Chatterjee (2009)[21] established that the most preferable grain size parameter is the well-sorted, medium sand. The present study has established that the Ebenebe sand deposit is dominantly medium–coarse grained and moderately well sorted. The Indian Standards (Bureau of Indian Standard, 1987-1974)[20] prescribed a narrow grading with not less than 70% of the grains retained in three consecutive meshes. A minimum of 95% of the grains should also be spread in four or five consecutive meshes to give sufficient permeability. These specifications are met by the Ebenebe sandstone. Not less than 75% of the sand grains are retained on three consecutive meshes (0 phi-2 phi), and not less than 95% of the grains are retained in four or five meshes (Tables 4.3).

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The Ebenebe Sandstone is therefore ideal for the foundry industry.

Table 4.3. Summary of the cumulative weight percentages for the fine to coarse grain size classes of the Ebenebe Sandstone in the study area

Locations	Class size (phi)			
	0.0-1.0 (phi) Coarse	01.-2.0 (phi) Medium	2.0-3.0 (phi) Fine	>3.0 (phi) Very fine
Ifite Awka (1)	70.82	21.34	3.92	3.92
Ifite Awka (2)	12.10	84.52	2.46	0.92
Ifite Awka (3)	59.54	29.20	10.44	0.82
Ifite Awka (4)	62.40	29.80	6.60	1.2
Isiagu (1)	66.44	30.50	2.80	0.26
Isiagu (2)	65.46	26.44	7.12	0.98
Isiagu (3)	82.34	12.02	4.24	1.40
Isiagu (4)	35.84	57.64	6.26	0.26
Enugu Abor (1)	19.46	67.62	9.86	3.06
Enugu Abor (2)	27.98	50.00	18.38	3.64
Enugu Abor (3)	32.84	60.42	5.54	1.20
Enugu Abor (4)	32.00	47.40	17.2	3.40

Water filtration

McLaws (1971)[17] and Chatterjee (2009)[21] have demonstrated that the basic criteria for selecting sand for filtration and water treatment purposes are the chemical composition, grain size distribution and grain shape. According to these researchers, chemical composition controls the inertness of the sand, preventing it from reacting with toxic substances inherent in waste water. The researchers thus prescribed a minimum of 80% SiO_2 a maximum of 90% of SiO_2, and a maximum of 2% for Fe_2O_3

Table 4.2 shows that whereas the silica requirement is met by the Ebenebe sand samples, the high values for Fe_2O_3 renders the sand unideal for water filtration and treatment.

The grain size of sand determines how fast water can be purified. Finer sands are preferable even though filtration is slower. Coarser sands provide quicker but ineffective filtration. The mean grain size of the Ebenebe

Sandstone as determined through sieve analysis in this study is coarse sand (1.0 phi). The implication is that the Ebenebe Sandstone will not be effective when used as a filtration material.

SUMMARY AND CONCLUSIONS

In contribution to the current effort of the Anambra State government to harness/exploit the solid mineral wealth in the state for industrial development, this paper has presented an integrated textural and geochemical analyses of the Ebenebe Sandstone deposit in Anambra State, and evaluated the suitability of the deposit as raw material for various industrial applications.

The following deductions are made from this study:

The Ebenebe Sandstone occurs as a sand ridge that extends from Ebenebe and trends in a slightly N-S direction, passing through Ugwuoba, Isiagu, Ufuma, Ajali and Umunze and beyond. in Anambra State.

The sand ridge which rises up to 500ft above sea level, and attains the maximum height in the vicinity of Umunze, is extensive is extensive enough to warrant commercial exploitation.

Grain size analysis shows that the sand is medium to coarse-grained, moderately well sorted, positively negatively skewed, and physically adequate for most industrial applications.

X-ray fluorescence studies revealed that the sandstone is a quartz arenite composed of about 90.5% silica content, with deleterious amounts of the oxides of aluminum, iron and titanium.

Even though the sandstone is texturally a suitable as raw material for the manufacture of various glass wares, the deposit does not have optimum silica concentration for the manufacture of glass wares and solar panels

Appropriate beneficiation processes however, will upgrade the chemical parameters to meet the desired specifications for the glass and solar panel industries.

The sand in its natural state suitable for the foundry industry.

Subject to detailed reserve estimation, environmental impact assessment and appropriate beneficiation processes, industrial exploitation of the sand deposit is thus strongly recommended to boost the economy of Anambra State.

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