ISSN 2229-5518

Local Substitute for Silica Flour In High Temperature High Pressure Enivronments

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Abstract— This paper centered on the development of a local substitute for silica flour. This was undertaken with the objectives of examining common indigenous materials to ascertain, if any may be a suitable replacement; thus breaking the reliance on imported Silica flour in Nigeria.

Sand; a common, cheap and readily available siliceous material, were collected randomly from the 3 senatorial districts of Delta state and Benin City. These sands were subjected to photomicrographic and grain size analyses. Based on the results, the Ughelli sands and the Benin sands were selected for in-depth investigation of early strength development and spectrometric study by infra-red, X-ray diffusion and X-ray fluorescence. 432 cements slurries were prepared with various proportions of API grade G cement, silica flour, Ughelli and Benin sands. These slurries were cured from 30 minutes to 120 minutes and their compressive strength determined at elevated pressure (5,000 to 10,000 psi) and temperature (200 to 350 degree Fahrenheit) conditions.

The investigation among other things studied the effect of a gradual substitution of indigenous sands for silica flour, traditionally used by the Petroleum Industry in Nigeria. Silica content in Ughelli sand is greater than 50%.Ughelli sands was observed to be suitable as a replacement for Silica flour (95%silica) at 60% substitution. It can therefore, be used for silicaceous enrichments of cements for deep Niger Delta oil field wells. These slurries were capable of withstanding pressure up to 9,500 psi and temperatures of 250 degrees Fahrenheit. Further research is recommended to factor –in the effect of the corrosive brine and waters at depths.

Index Terms—Niger Delta, Silica Flour, Ughelli sand

1 INTRODUCTION

THIS is a study on the effect(s) of elevated pressures (5,000 to 10,000 psi) and temperatures (200 to 350 degrees Fahrenheit) on API grade G cement –silica flour systems. It centered on the replacement of the silica flour with an indigenous Nigerian material. For this investigation the following method was adapted:

2 METHODOLOGY

2.1 Sampling Technique

After an extensive literature review on the fatigue performance of cement [1],[2],[3] and the Nigerian high pressure, high temperature scenario [4],[5]; a sampling technique was selected for the investigation; this involved an initial survey by random sampling. A total of nine sands were randomly collected from the 3 senatorial districts of Delta State (seven samples) and Benin City (two samples). These samples were subjected to photomicrographic and grain size analyses. (Table 1)

2.2 Photomicrography Studies

Thin-sections were produced from the sands. Photomicrograph was made from the thin sections. These were examined under cross polarized and plane polarized light to reveal the mineralogical make-up of the sands as shown in the appendix. (Figures 1 to 9)

2.3 Grain Size Analyses

Grain size analyses were done to determine the particle size distribution; as the reactivity of any substance is partially dependent on the respective sizes of the reacting species. The logarithmic Udden–Wentworth grade scale was used in order to place equal emphasis on small differences in fine particles and larger differences in coarse particles. [6], [7] Results were analysed with grain size statistics software GRADISTAT [8] (Figures 10-18).

Based on the results of these preliminary investigations, the Ughelli and Benin sands were selected for further investigation at elevated pressure-temperature conditions for strength development and spectrometry study. (Figures 19-22), [9], [10] XR-D of Benin (Figure 19) and Ughelli sands (Figure 20) were compared.The bond structure of these sands were also analysed and compared with Silica flour , normally used in Nigeria to prevent cement retrogression.

3 SAMPLES PREPARATION

Cement slurries were prepared from API grade G, silica flour and sands in various proportions. The sands were used to gradually substitute for the silica flour. The prepared cement slurry specimen was placed in the mould of known cross-sectional area and cured for 30 -120 minutes before strength development at elevated conditions were investigated.

4 INVESTIGATION AT ELEVATED CONDITIONS

The behavoiur of the cement slurries in high pressure, high temperature environment was created in the laboratory to mimic (simulate) the conditions at depth. A device was designed to supply a regulated quantity of heat via a heating element. Heat supply was synchronized via a regulator. Because of the high temperature involved, temperature measurements were done using a thermocouple, [11] By simultaneously subjecting the cement slurries to the effect of the Univer-

ISSN 2229-5518

sal Compression Tester (to generate the necessary pressure) and the heating device, a high pressure, high temperature environment was mimicked (simulated).

4.1 Compressive Strength Determination at Elevated Pressure (s) and Temperature(s)

Six different types of cement slurries were prepared, using API grade G cement, Silica Flour, Benin sands, Ughelli sands in various proportions. Slurries of Neat API grade G cements and Ordinary Portland cement were prepared as "controls" and used to determine cements' response in the absence of all additives. Pressure readings were incremented by a factor of 1,000psi while the temperature readings were incremented by 50 ^{0}F. A total of 432 readings were taken.

This paper would consider data for the Ughelli sands analysis only (Table 1).

Table 1: Compressive Strength Analysis for 30 minutes curing time

S/N	Lab temp ,deg F	Silica flour, dry wt. ,gram	Ughelli sands, , dry wt. ,gram	API Grade G cement, , dry wt. ,gram	Temp. deg F
1	80.06	2,080.00	6,500.00	19,500.00	200
2	77	2,080.00	6,500.00	19,500.00	200
3	75.2	2,080.00	6,500.00	19,500.00	200
4	77	2,080.00	6,500.00	19,500.00	200
5	77	2,080.00	6,500.00	19,500.00	200
6	75.2	2,080.00	6,500.00	19,500.00	200
7	75.2	2,080.00	6,500.00	19,500.00	300
8	75.2	2,080.00	6,500.00	19,500.00	300
9	75.2	2,080.00	6,500.00	19,500.00	300
10	75.2	2,080.00	6,500.00	19,500.00	300
11	75.2	2,080.00	6,500.00	19,500.00	300
12	75.2	2,080.00	6,500.00	19,500.00	300
13	75.2	4,680.00	3,900.00	18,720.00	250
14	75.2	4,680.00	3,900.00	18,720.00	250
15	75.2	4,680.00	3,900.00	18,720.00	250
16	75.2	4,680.00	3,900.00	18,720.00	250
17	75.2	4,680.00	3,900.00	18,720.00	250
18	75.2	4,680.00	3,900.00	18,720.00	250
19	75.2	4,680.00	3,900.00	18,720.00	350
20	75.2	4,680.00	3,900.00	18,720.00	350
21	75.2	4,680.00	3,900.00	18,720.00	350
22	75.2	4,680.00	3,900.00	18,720.00	350
23	75.2	4,680.00	3,900.00	18,720.00	350
24	75.2	4,680.00	3,900.00	18,720.00	350
25	75.2	6,500.00	1,300.00	18,200.00	200
26	75.2	6,500.00	1,300.00	18,200.00	200
27	75.2	6,500.00	1,300.00	18,200.00	200
28	75.2	6,500.00	1,300.00	18,200.00	200
29	75.2	6,500.00	1,300.00	18,200.00	200
30	75.2	6,500.00	1,300.00	18,200.00	200
31	75.2	6,500.00	1,300.00	18,200.00	300
32	75.2	6,500.00	1,300.00	18,200.00	300
33	75.2	6,500.00	1,300.00	18,200.00	300
34	75.2	6,500.00	1,300.00	18,200.00	300
35	75.2	6,500.00	1,300.00	18,200.00	300
36	75.2	6,500.00	1,300.00	18,200.00	300
37	75.2	2,080.00	5,770.00	18,900.00	250
38	75.2	2,080.00	5,770.00	18,900.00	250
39	75.2	2,080.00	5,770.00	18,900.00	250
40	78.8	2,080.00	5,770.00	18,900.00	250
41	77	2,080.00	5,770.00	18,900.00	250
42	77	2,080.00	5,770.00	18,900.00	250

Only a subset of these readings would be considered in this paper. The readings for a curing time of 30 minutes were analyzed as the development of early strength is crucial for casing placement, competence and the economy. (Figure 23)

Table 2: List of Sands investigated

Sample	Content
Sands 001	Sands from the river bank, River Niger, Asaba Delta state
Sands 002	Benin sands. Collected at a depth of 97.8 ft from a privately –operated quarry
Sands 003	Benin sands. Collected at a depth of 82.5 ft from a privately –operated quarry
Sands 004	Oleh sands. Surface. Sands collected from Engineering workshop area, Delta State University, Abraka, Oleh Campus
Sands 005	Oleh sands. Surface. Sands collected from Undergraduate Engineering complex area, Delta State University, Abraka, Oleh Campus
Sands 006	Ughelli sands. Collected from the bank of Ughelli river, Ughelli LGA
Sands 007	River Bank, Owhe-Oleh, Delta state. At private sand wining operation site.
Sands 008	Uphill, Owhe-Oleh (Delta state)
Sands 009	Abraka , McCarty beach

5 SPECTROMETRY EXAMINATIONS

Spectrometric investigations were undertaken. This involves infra-red analysis, XR-D. (Figures 10 to 13)

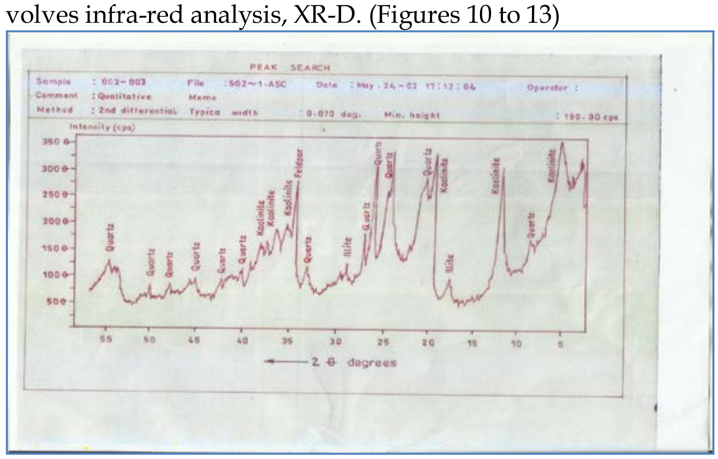

Figure 19 XR-D of Benin Sand

The spectrometry examinations revealed the chemical composition and confirm the provenance as suggested from the grain size analysis. Samples were prepared for examination by first crushing and pulverizing with an electric crusher for 60 seconds using the Herzog gyro-mill (Simatic C7-621). Pellets were prepared from the pulverized samples; first by grinding 20 grams of each sample with 0.4 g stearic acids for 60 seconds. After each grinding the Gyro mill was cleaned to avoid contamination; a binding agent was prepared using stearic acid and the Herzog pelletizing equipment was used to press the sample to a pressure of 200KN for 60 seconds, and form pellets. These 2mm pellets were added into a sample holder of the X-ray equipment (Philips PW-166) for analysis.

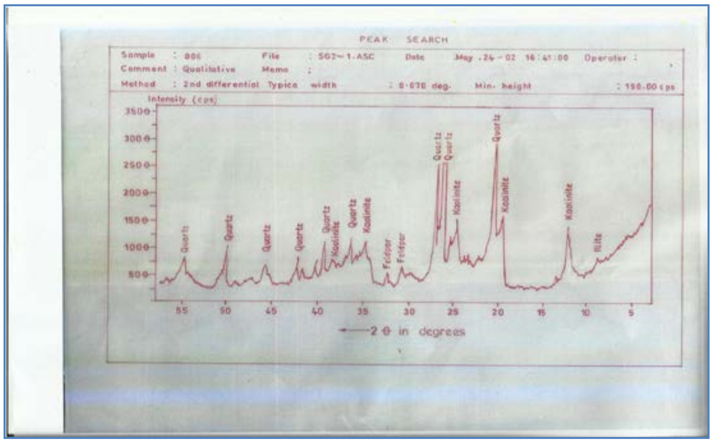

Figure 20 XR-D of Ughelli Sand

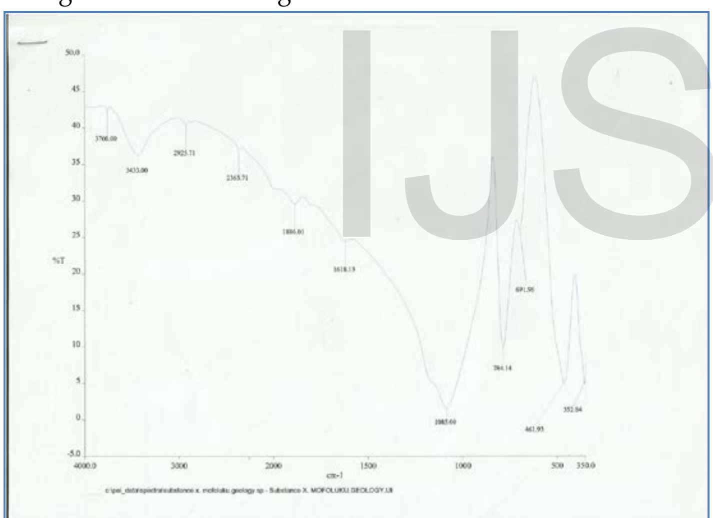

Figure 21 IR- of Silica Flour

6 CONCLUSIONS

The following are the conclusion from the study:

1. The results of the study showed that the Ughelli sands can be used as an acceptable substitute for the expensive imported Halliburton Silica flour within the temperature-pressure conditions studied.
2. The variances in all the slurries made with Ughelli sands were observed to be 0.1.
3. Among all the sands examined, the Ughelli sands showed the best promise for use in high pressure, high temperature environment.
4. The more finely grinded the Ughelli sands were the larger the surface area and the quicker the reaction.
5. Benin City sands with a lower SiO_4 content if to be used in high pressure, high temperature terrain would require a greater amount of silica flour than the Ughelli sands per weight of API grade G cement used.
6. It was observed that at constant composition and curing time, the effects of change in temperature on compressive strength were not pronounced at the temperature pressure range of investigation (200-350 degrees Fahrenheit and 5,000 to 10,000 psi) when compared to the effect of increasing curing time (from 30 minutes to 60 minutes) at constant composition.
7. This study among other things identified the use of indigenous sands for siliceous enrichments of high pressure, high temperature oilfield cement slurries for Niger Delta wells.

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ISSN 2229-5518

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APPENDICES

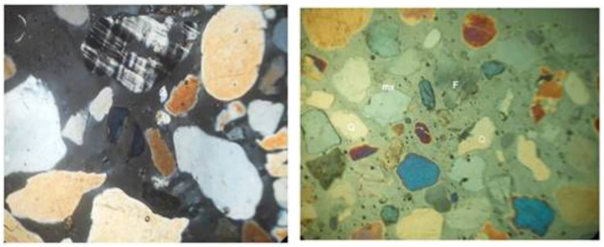


Figure 1 Sand001 under plane and cross polarized light.

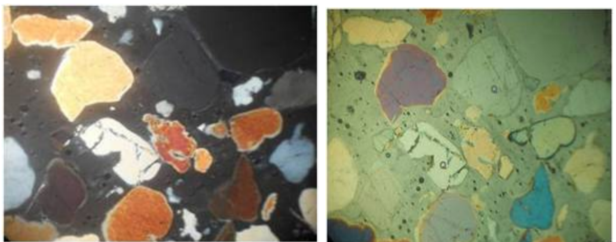


Figure 2 Sand002 under plane and cross polarized light

Figure 3 Sands 003 under plane and cross polarized light

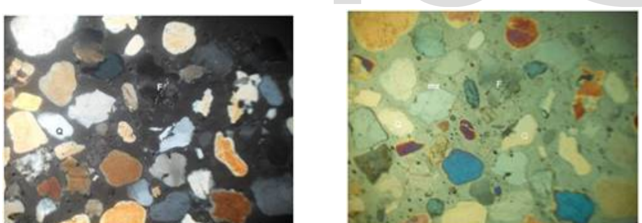


Figure 4 Sands004 under plane and cross polarized light.

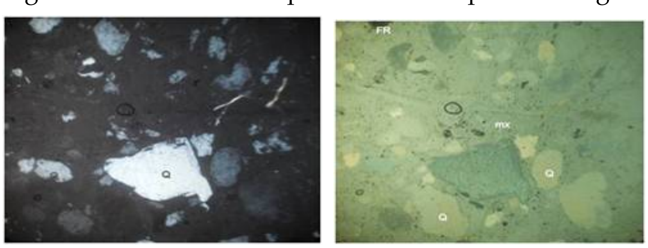


Figure 5 Sands005 under plane and cross polarized light

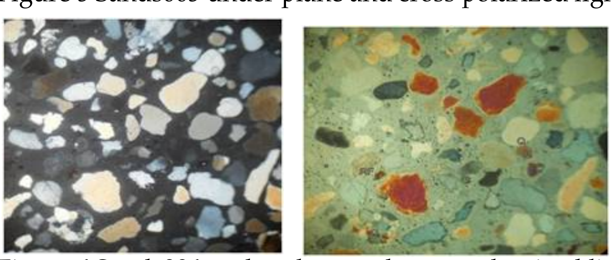


Figure 6 Sands006 under plane and cross poloarized light.

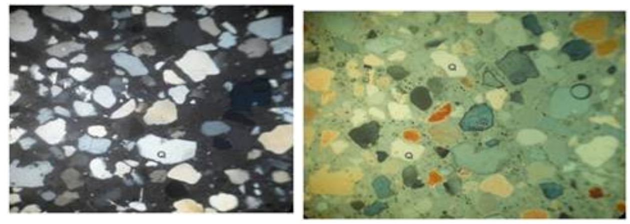


Figure 7 Sands007 under plane and cross polarized light.

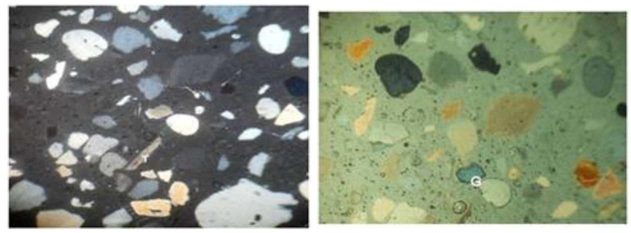


Figure 8 Sands008 under plane and polarized light.

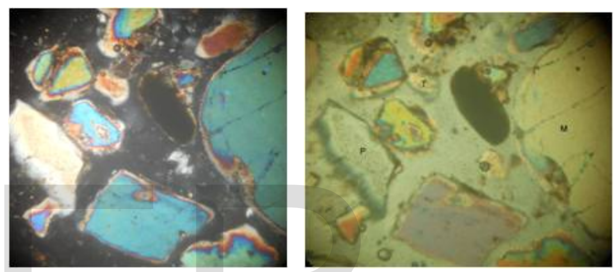
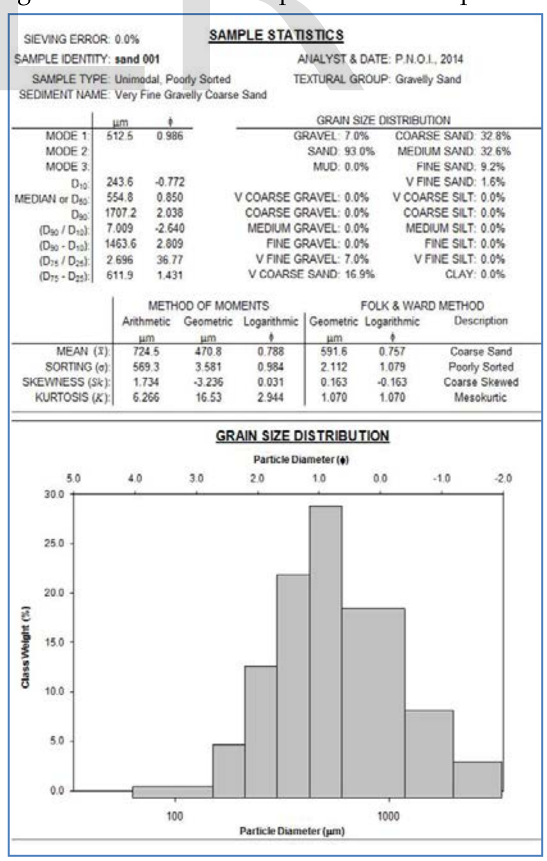


Figure 9 Sands009 under plane and cross polarized light.



SAMPLE STATISTICS

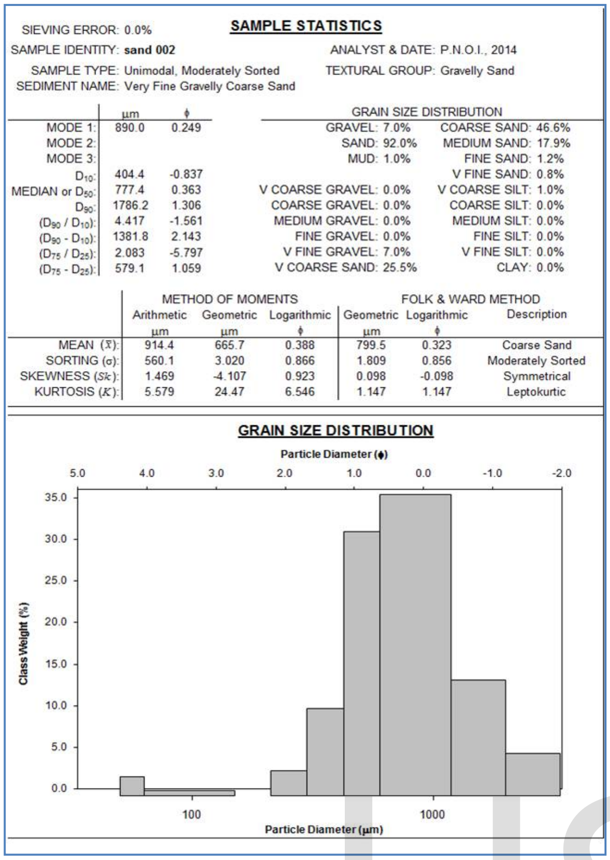
SIEVING ERROR: 0.0%
SAMPLE IDENTITY: **sand 001** ANALYST & DATE: P.N.O.I., 2014
SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Coarse Sand

	μm	ϕ
MODE 1:	512.5	0.986
MODE 2:		
MODE 3:		
D_{10}:	243.6	-0.772
MEDIAN or D_{50}:	554.8	0.850
D_{90}:	1707.2	2.038
(D_{90} / D_{10}):	7.009	-2.640
$(D_{90} - D_{10})$:	1463.6	2.809
(D_{75} / D_{25}):	2.696	36.77
$(D_{75} - D_{25})$:	611.9	1.431

GRAIN SIZE DISTRIBUTION			
GRAVEL:	7.0%	COARSE SAND:	32.8%
SAND:	93.0%	MEDIUM SAND:	32.6%
MUD:	0.0%	FINE SAND:	9.2%
		V FINE SAND:	1.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	7.0%	V FINE SILT:	0.0%
V COARSE SAND:	16.9%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	724.5	470.8	0.788	591.6	0.757	Coarse Sand
SORTING (σ):	569.3	3.581	0.984	2.112	1.079	Poorly Sorted
SKEWNESS (Sk):	1.734	-3.236	0.031	0.163	-0.163	Coarse Skewed
KURTOSIS (K):	6.266	16.53	2.944	1.070	1.070	Mesokurtic

Figure 10 Grain size analyses for sands001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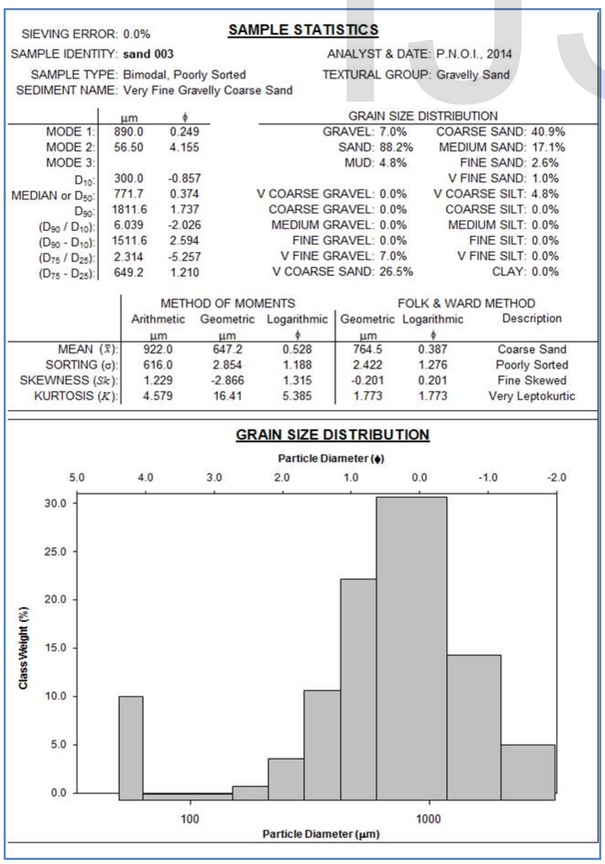
SAMPLE IDENTITY: sand 002 — ANALYST & DATE: P.N.O.I., 2014
SAMPLE TYPE: Unimodal, Moderately Sorted — TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Coarse Sand

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	890.0	0.249	GRAVEL:	7.0%	COARSE SAND:	46.6%
MODE 2:			SAND:	92.0%	MEDIUM SAND:	17.9%
MODE 3:			MUD:	1.0%	FINE SAND:	1.2%
D_{10}:	404.4	-0.837			V FINE SAND:	0.8%
MEDIAN or D_{50}:	777.4	0.363	V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.0%
D_{90}:	1786.2	1.306	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	4.417	-1.561	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	1381.8	2.143	FINE GRAVEL:	0.0%	FINE SILT:	0.0%
(D_{75} / D_{25}):	2.083	-5.797	V FINE GRAVEL:	7.0%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	579.1	1.059	V COARSE SAND:	25.5%	CLAY:	0.0%

	METHOD OF MOMENTS Arithmetic μm	Geometric μm	Logarithmic ϕ	FOLK & WARD METHOD Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	914.4	665.7	0.388	799.5	0.323	Coarse Sand
SORTING (σ):	560.1	3.020	0.866	1.809	0.856	Moderately Sorted
SKEWNESS (Sk):	1.469	-4.107	0.923	0.098	-0.098	Symmetrical
KURTOSIS (K):	5.579	24.47	6.546	1.147	1.147	Leptokurtic

Figure 11 Grain size analyses for sands002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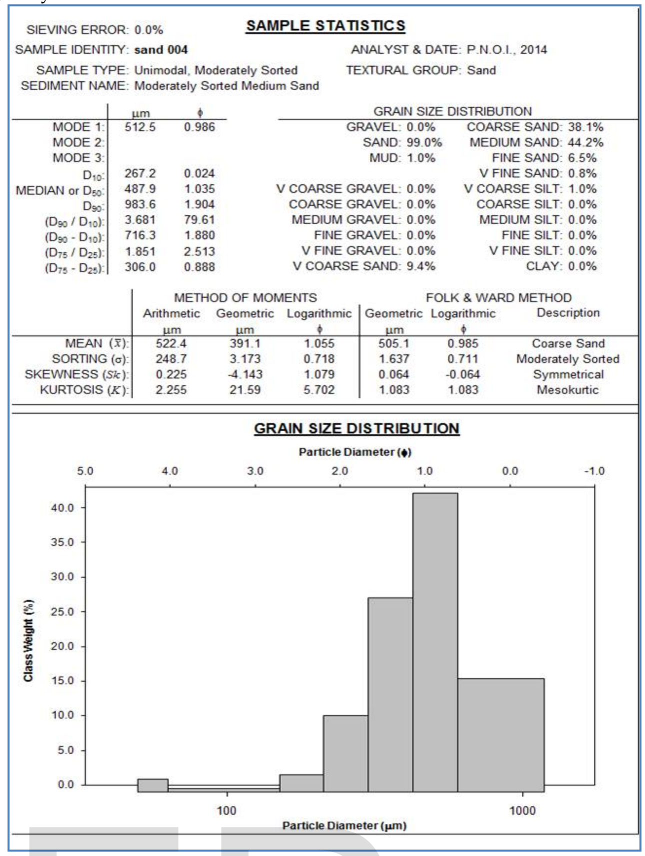
SAMPLE TYPE: Bimodal, Poorly Sorted — TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Coarse Sand

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	890.0	0.249	GRAVEL:	7.0%	COARSE SAND:	40.9%
MODE 2:	56.50	4.155	SAND:	88.2%	MEDIUM SAND:	17.1%
MODE 3:			MUD:	4.8%	FINE SAND:	2.6%
D_{10}:	300.0	-0.857			V FINE SAND:	1.0%
MEDIAN or D_{50}:	771.7	0.374	V COARSE GRAVEL:	0.0%	V COARSE SILT:	4.8%
D_{90}:	1811.6	1.737	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	6.039	-2.026	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	1511.6	2.594	FINE GRAVEL:	0.0%	FINE SILT:	0.0%
(D_{75} / D_{25}):	2.314	-5.257	V FINE GRAVEL:	7.0%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	649.2	1.210	V COARSE SAND:	26.5%	CLAY:	0.0%

	METHOD OF MOMENTS Arithmetic μm	Geometric μm	Logarithmic ϕ	FOLK & WARD METHOD Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	922.0	647.2	0.528	764.5	0.387	Coarse Sand
SORTING (σ):	616.0	2.854	1.188	2.422	1.276	Poorly Sorted
SKEWNESS (Sk):	1.229	-2.866	1.315	-0.201	0.201	Fine Skewed
KURTOSIS (K):	4.579	16.41	5.385	1.773	1.773	Very Leptokurtic

Figure 12 Grain size analyses for sands003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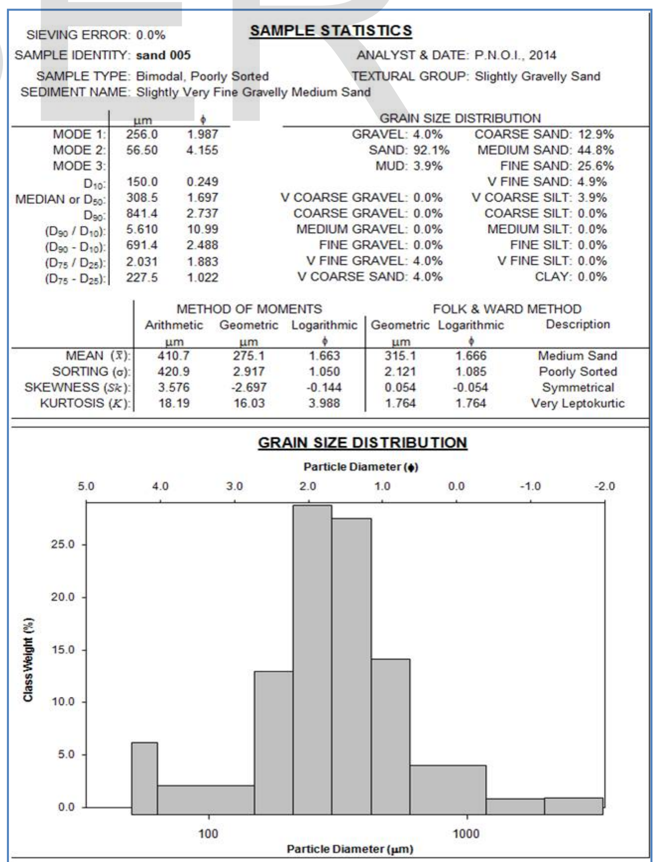
SAMPLE TYPE: Unimodal, Moderately Sorted — TEXTURAL GROUP: Sand
SEDIMENT NAME: Moderately Sorted Medium Sand

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	512.5	0.986	GRAVEL:	0.0%	COARSE SAND:	38.1%
MODE 2:			SAND:	99.0%	MEDIUM SAND:	44.2%
MODE 3:			MUD:	1.0%	FINE SAND:	6.5%
D_{10}:	267.2	0.024			V FINE SAND:	0.8%
MEDIAN or D_{50}:	487.9	1.035	V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.0%
D_{90}:	983.6	1.904	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	3.681	79.61	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	716.3	1.880	FINE GRAVEL:	0.0%	FINE SILT:	0.0%
(D_{75} / D_{25}):	1.851	2.513	V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	306.0	0.888	V COARSE SAND:	9.4%	CLAY:	0.0%

	METHOD OF MOMENTS Arithmetic μm	Geometric μm	Logarithmic ϕ	FOLK & WARD METHOD Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	522.4	391.1	1.055	505.1	0.985	Coarse Sand
SORTING (σ):	248.7	3.173	0.718	1.637	0.711	Moderately Sorted
SKEWNESS (Sk):	0.225	-4.143	1.079	0.064	-0.064	Symmetrical
KURTOSIS (K):	2.255	21.59	5.702	1.083	1.083	Mesokurtic

Figure 13 Grain size analyses for sands004


SIEVING ERROR: 0.0% — SAMPLE STATISTICS
SAMPLE IDENTITY: sand 005 — ANALYST & DATE: P.N.O.I., 2014
SAMPLE TYPE: Bimodal, Poorly Sorted — TEXTURAL GROUP: Slightly Gravelly Sand
SEDIMENT NAME: Slightly Very Fine Gravelly Medium Sand

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	256.0	1.987	GRAVEL:	4.0%	COARSE SAND:	12.9%
MODE 2:	56.50	4.155	SAND:	92.1%	MEDIUM SAND:	44.8%
MODE 3:			MUD:	3.9%	FINE SAND:	25.6%
D_{10}:	150.0	0.249			V FINE SAND:	4.9%
MEDIAN or D_{50}:	308.5	1.697	V COARSE GRAVEL:	0.0%	V COARSE SILT:	3.9%
D_{90}:	841.4	2.737	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	5.610	10.99	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	691.4	2.488	FINE GRAVEL:	0.0%	FINE SILT:	0.0%
(D_{75} / D_{25}):	2.031	1.883	V FINE GRAVEL:	4.0%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	227.5	1.022	V COARSE SAND:	4.0%	CLAY:	0.0%

	METHOD OF MOMENTS Arithmetic μm	Geometric μm	Logarithmic ϕ	FOLK & WARD METHOD Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	410.7	275.1	1.663	315.1	1.666	Medium Sand
SORTING (σ):	420.9	2.917	1.050	2.121	1.085	Poorly Sorted
SKEWNESS (Sk):	3.576	-2.697	-0.144	0.054	-0.054	Symmetrical
KURTOSIS (K):	18.19	16.03	3.988	1.764	1.764	Very Leptokurtic

Figure 14 Grain size analyses for sands005

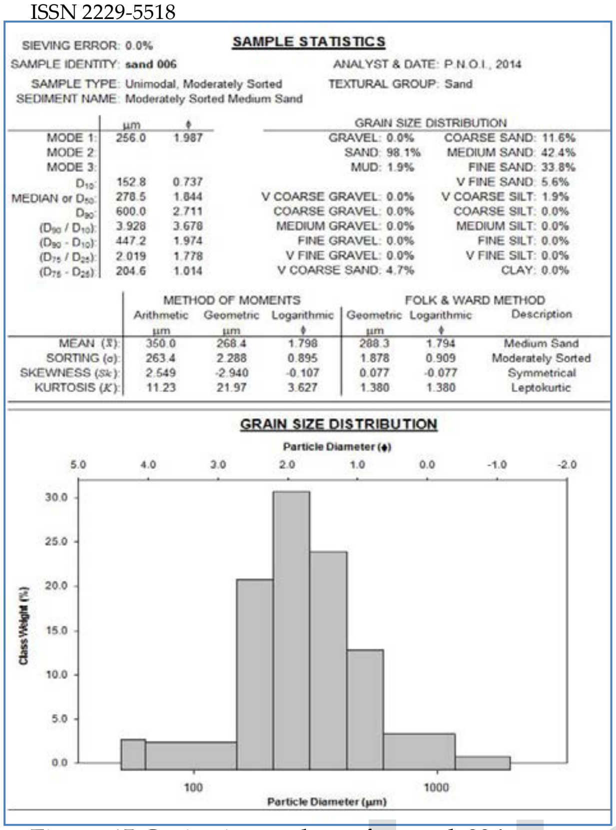


Figure 15 Grain size analyses for sands006

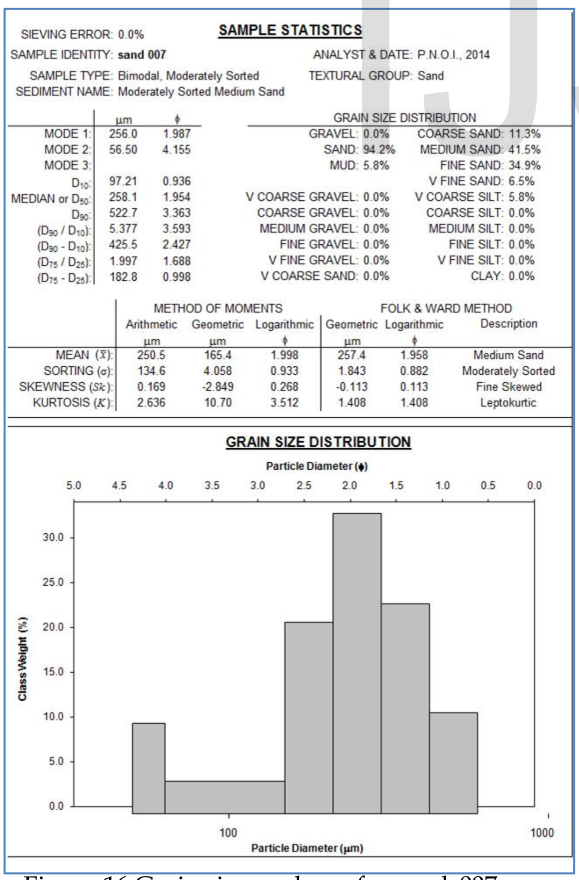


Figure 16 Grain size analyses for sands007

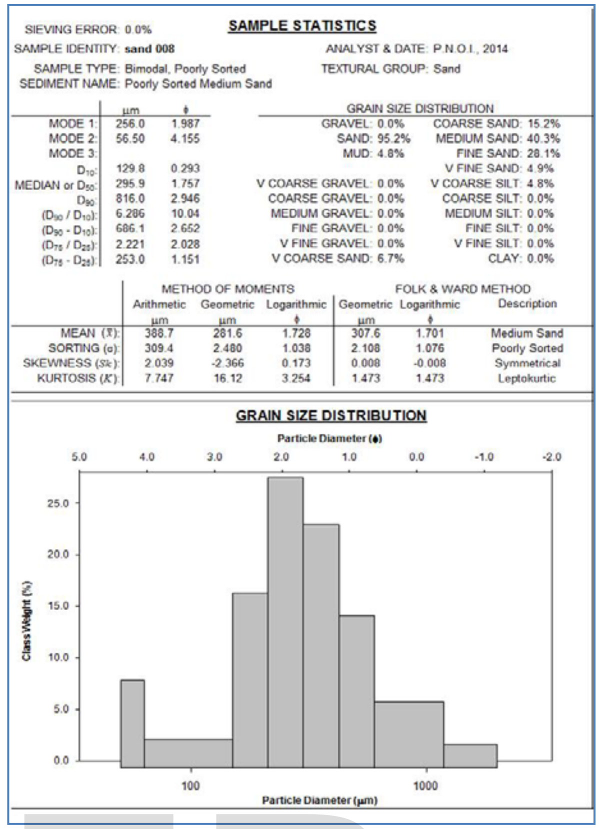


Figure 17 Grain size analyses for sands008

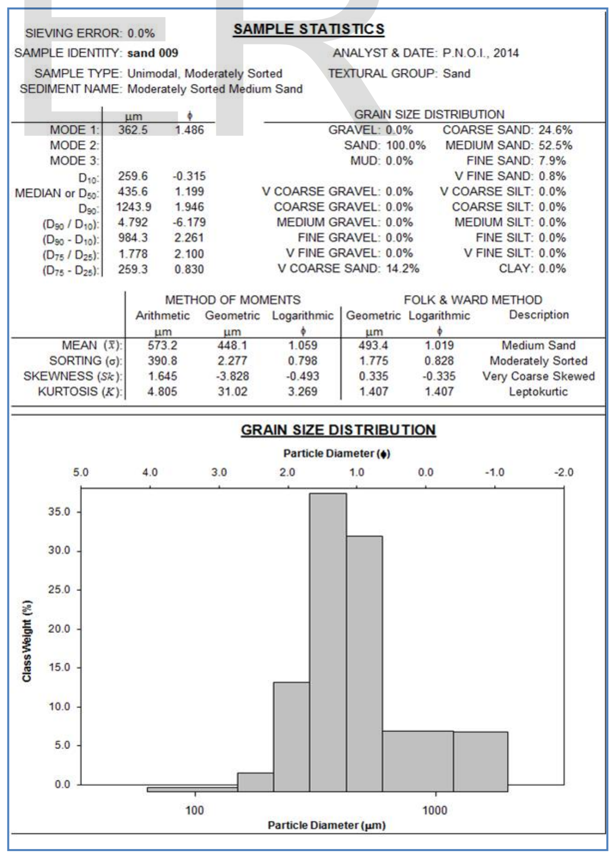


Figure 18 Grain size analyses for sands009