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Sedimentological Aspects of Subcropping Sand Units Within Imo Formation, Western Niger Delta Basin

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Abstract

Aquiferous sand units of the Imo Formation have been recently reported to contain warm groundwater around Ofumwengbe community, near Benin City, western Niger Delta Basin, Nigeria. Whereas investigations into the sedimentological aspects of sand members in the Imo Formation outcropping in central and eastern Niger Delta have been documented in literature, reports on the sedimentological aspects of sand members within the Imo formation in the western Niger Delta are either nonexistent or publicly unavailable. This dearth of data provides the impetus for this study, which aims to evaluate the sedimentological aspects of sand members within the Imo formation in the western Niger Delta. Six (06) ditch cutting samples were obtained from the aquiferous section of two (02) warm groundwater wells in the study area. The methodology employed entailed visual lithology characterization using a standard comparator, acid test and granulometry (sieve analysis). The results obtained show that the samples display strong effervescence, and possess dominantly medium grained, leptokurtic, negatively (coarse) skewed, well sorted subangular to subrounded sand sized quartzose framework particles, which have attained submature to mature textural maturity. The aforementioned results when integrated with inferences drawn from binary discriminant plot, models and multivariate statistics indicate a near shore shallow marine paleoenvironment; with fluvial influence was prevalent in this area during the Thanetian age.

1. Introduction

Sand facies within the Imo Formation, Niger Delta which is the object of this study has been proven to be aquiferous in parts of Ofumwegbe Community and environs near Okada (Fig. 1), Northern Niger Delta Basin region of Nigeria. Warm groundwater occurrence (up to 52^{0}C) was recently reported from a number of water wells drilled around this community. Reports on the sedimentological aspects of sand members within the Imo formation in this area are either unavailable or inaccessible to the scientific community perhaps due to paucity of outcrops. However, there are reports of outcrops in a few places in central and eastern Niger Delta such as: Ebenebe–Awka, and Ozu-Akoli – Amaeke axis, Ugwuoba, etc [1, 2, 3, 4, 5, 6]. An evaluation of these outcropping sand units resulted in the identification of Ebenebe, Umuna and Igbaku sand members within the Imo Formation [4]. Lithologically, the characteristics of these sand members are described as dominantly medium to coarse, well sorted quartzose framework with trace fossils typical of agitated shoreline environment [2, 3, 5, 6]. Whereas textural descriptions of sand members within the Imo Formation exist Central and Eastern Niger Delta Basin [1, 2, 3 4, 5, 6], very little information on the textural characteristics of the Imo Formation sand facies in the Northern Depobelt exist. Interestingly, several unpublished reports from hydrocarbon wells such as Akukwa-II, Igbariam-1, Iji-1, Okpo-1, Anambra River 1, 2, 3 hydrocarbon wells in central and eastern Niger Delta show good development of these sand bodies. Notwithstanding our inability to provide information on the primary sedimentary structures preserved in this unit in this area due to the nature of samples, this study provides insight into the textural characteristics as well as depositional conditions of this sand member, which will prove valuable in understanding the Thanetian Paleogeography of the Niger Delta Basin.

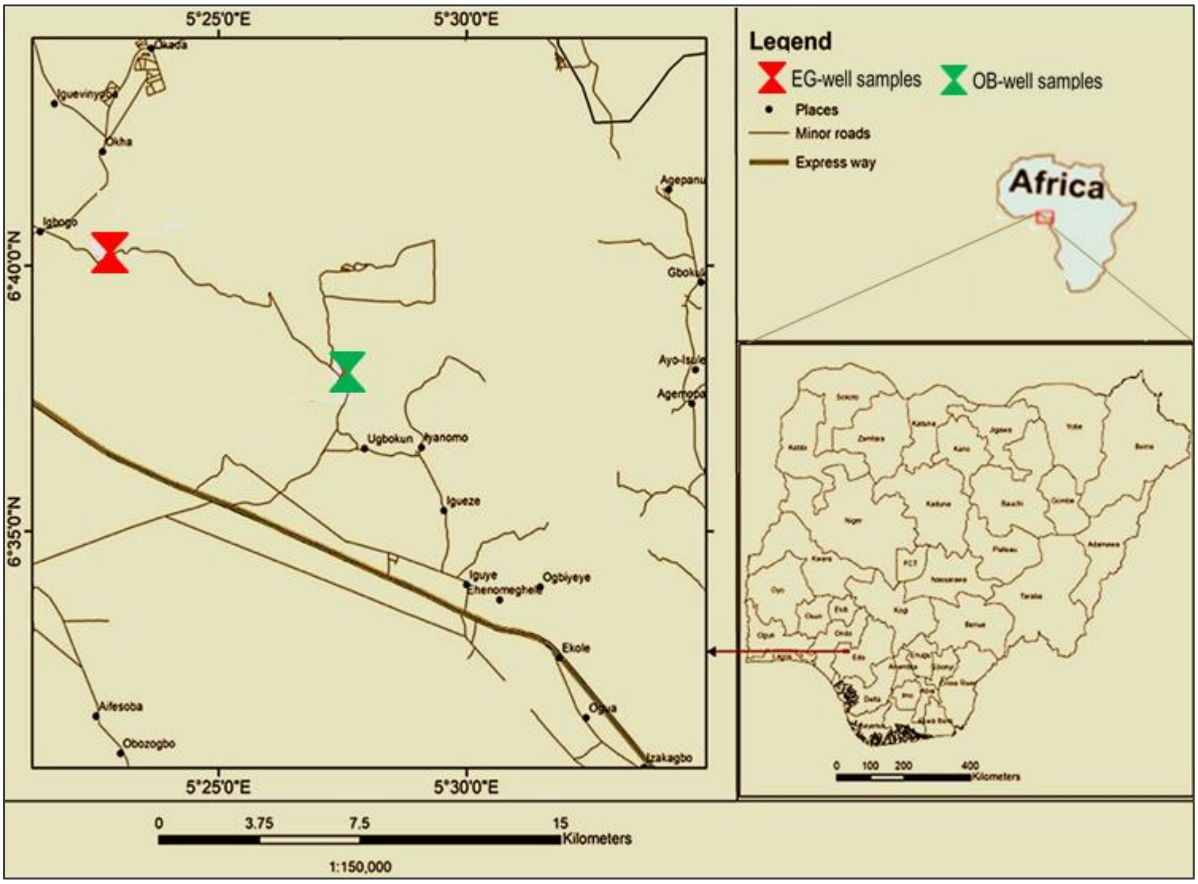

Fig. 1: location map of study area

2.0 Geology and Tectonic setting

The Niger Delta Basin is a 75,000 sq. km. clastic, wedge which represents that final phase of the Benue Trough. The Anambra Basin and Atlantic Ocean respectively represents its northern and southern limits, while its eastern and western limits are the Benin and Calabar hingelines respectively.

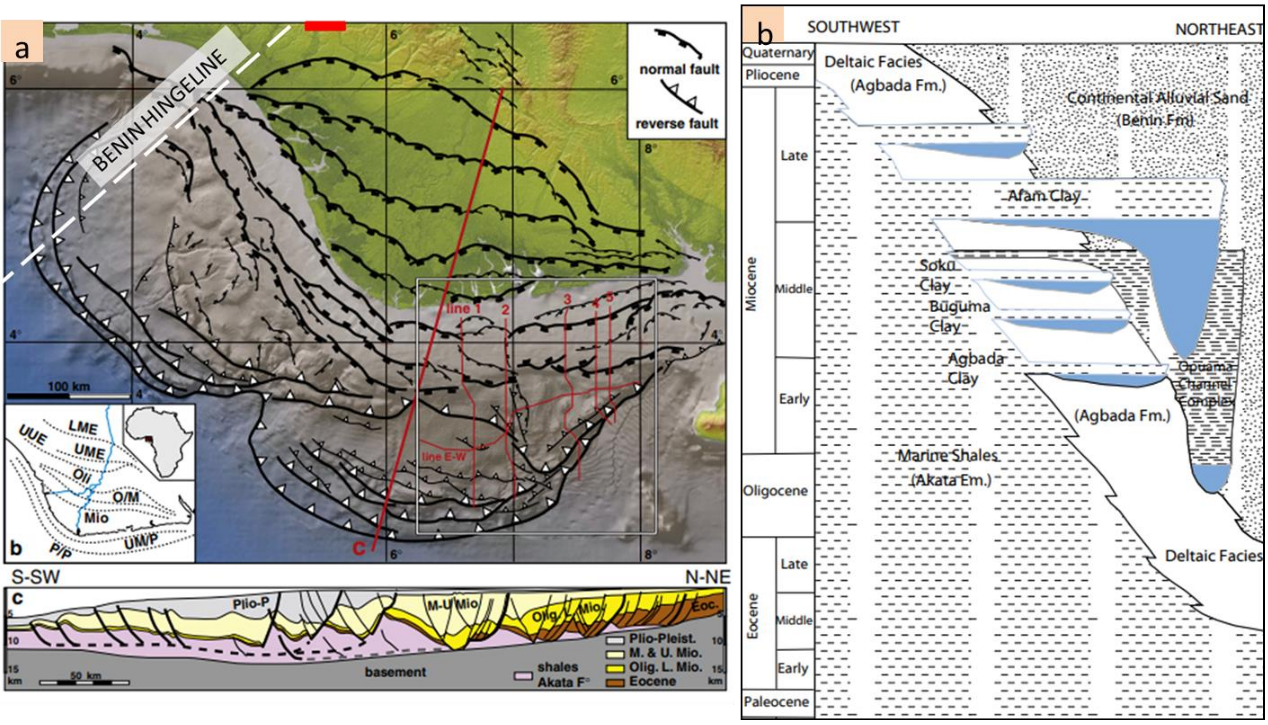

Fig. 2, a: Map of Niger Delta showing study area (red box), depobelts and structural domains modified after [7]; b: Lithostratigraphy of Niger Delta basin from NE-SW transect [8].

Structurally, the Niger-delta Basin is a passive margin basin. It is underlain by continental lithosphere in its up-dip end and transitional to oceanic crust down-dip. A North-South cross-section reveals a structural framework which is a consequence of the prevailing gravity driven tectonics [gravity spreading[9], characterized by three (03) underlying structural domains (Fig. 2a), which are: 1) an proximal updip extensional realm wherein listric growth faults predominates; 2) a middle translational realm wherein mudstone diapirs are common; 3) and a distal compressional realm wherein thrust faults predominates [10, 7, 11]. Five (05) smaller regional sub-basins or depobelts have been demarcated, each limited by down to the basin regional and counter regional bounding faults. [12, 13]. These depobelts which become progressively younger southwards are: the Northern Delta, the Greater Ughelli, the Central Swamp I & II, the Coastal Swamp and the offshore depobelts.

The Basin's lithostratigraphic units are time transgressive, consisting of the Benin Formation, the Agbada Formation and the Akata Formation (Fig. 2b) in stratigraphic order, with thickness upto 12 km [14, 12, 15, 13]. The subcropping Akata Formation, which is co-eval with the Ewekoro Formation in the Benin Basin outcrops updip as the Imo Formation, consists primarily of mudstones and subordinate sand facies. Its thickness varies from up to 7km updip to about 5km downdip. The overlying subcropping Agbada Formation outcrops as the Ameki and Ogwashi-Asaba formations updip. It comprises of up to 3.5 km thick succession of sand-mudstone intercalations of [9]. The lower segment of this lithostratigraphic unit show greater mudstone thickness which reduces up section (stratigraphy). The overlying outcropping Benin Formation comprises of gravels, sands, clays, peat and ironstone units, which could get up to 2 km in thickness.

2.2 Local Geology

The wells within Ofumwengbe community lie within the oldest depobelt of the Niger-delta Basin-the Northern depobelt, wherein the Imo Formation outcrops. The deposition of the Imo Formation was consequent upon the Thanetian flooding which enveloped the Upper Cretaceous-Danian sediments of the Anambra Basin [4, 5]. Up to 1000m of sediment thickness has been reported along the Imo River [16]. Lithologically, the Imo Formation has been described as consisting predominantly of grey calcerous mudrocks, with subordinate sand [Ebenebe, Umuna and Igbaku] members [4] and infrequent limestone and ironstone units. Mineralogically, kaolinite and quartz predominates with minor amounts of montmorillonite, illite, calcite, rutile, ilmenite and haematite [17]. The Imo Formation contains copious amounts of micro and macro fossils such as forams, ostracods, bivalves, gastropods and cephalopods. Diagnostic species of the aforementioned alongside sedimentological analysis have supported a shelfal paleoenvironment [16, 18, 1, 4, 5, 6]. Stratigraphic control was established from (unpublished) index palynomorphs index specimens such as: *Retidiporities magdalenensis and Longapertites vaneendenburg*, *Verrucatosporites usmensis, Ifecysta sp., Kallosphaeridium cf. yorubaensis and Adnatosphaeridium sp*., which confirm a Middle to Late Paleocene age for the sediments of the Imo Formation penetrated by the wells.

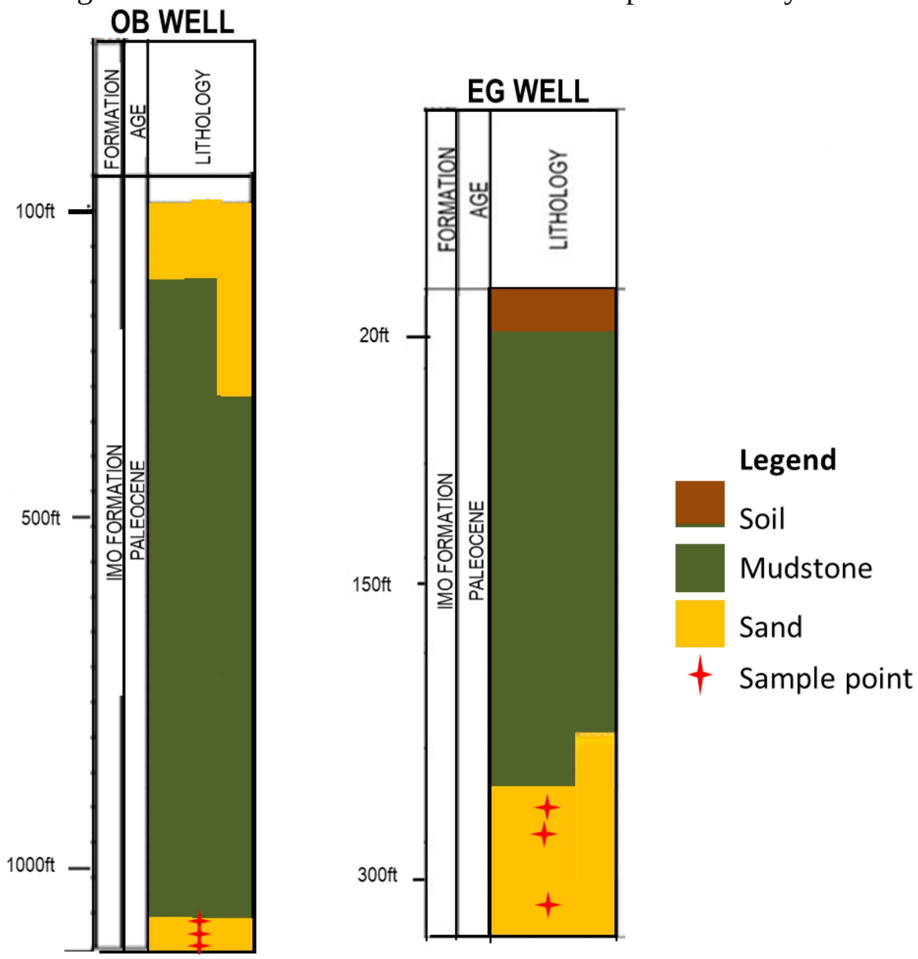

Fig. 3: Lithologic Column of OB and EG wells

3.0 Materials and Method

Seventy-four (74) samples comprising sixty-eight samples (68) from the non-aquifer section and six (06) samples from the aquifer section were obtained from OB and EG wells drilled by Edo State Government around Ofunmwegbe community, near Okada. The lithological characteristics of the samples were described before subjecting about 1 g of the materials to effervescence test with dilute Hydrochloric acid (0.5M). The effervescence test technique of $CaCO_3$ estimation is an in-house technique hinged on the widely known fact that $CaCO_3$ reacts with HCl to give off CO_2, evidenced by effervescence. Therefore, the degree of effervescence is directly proportional to the Concentration of CaCO3 in the sample. Following this background, a subjective visual scheme of quantitatively estimating the concentration of $CaCO_3$ in sediment samples has been developed based on the degree of effervescence observed from each sample. In this scheme, a zero (0) effervescence depict the absence of $CaCO_3$ in the sample. A value of 1on the scheme represent an observation of weak (mild) effervescence, depicting low concentration of $CaCO_3$., where as a value of 2 represent an observation of moderate degree of effervescence, depicting a moderate concentration of $CaCO_3$ in the sample. Furthermore, a value of 3 on the scheme represent an observation of strong degree of effervescence, depicting a high concentration of $CaCO_3$ in the sample.

The remaining portions of the six (06) samples from the aquifer section of wells OB (1080-1090ft, 1090-1100 ft and 1100-1110ft) - and EG (230ft, 250 and 330ft) were subjected to visual particle size analysis and dry sieve (50g) analysis using stereo microscope (aided by comparator) and set of sieves respectively. After dry sieving, the individual weight of sample retained in each sieve was recorded, followed by computation of individual weight percent as well as the cumulative weight percentage. A cumulative frequency curve (ogive) of particle diameter (mm) versus cumulative weight percent was plotted thereafter. The corresponding values of the following percentile; 5%, 16%, 25%, 50%, 75%, 84% and 95% were read off from the ogive curve. These were used to calculate the statistical parameters of standard deviation, skewness, kurtosis, mean and median as shown below. Equations 1-4 [19] were used to derive the various grain size parameters.

$$\text{Median} = \phi 50$$

$$\text{Graphic Mean (Mz)} = \frac{\phi 16 + \phi 50 + \phi 84}{3} \qquad \text{(1)}$$

$$\text{Inclusive Graphic Standard Deviation } \sigma i \text{ (sorting)} = \frac{\phi 84 - \phi 16 + \phi 84}{4} + \frac{\phi 95 - \phi 5}{6} \qquad \text{(2)}$$

$$\text{Inclusive Graphic Skewness (Ski)} = \frac{\phi 84 - \phi 16 + 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2\phi 50}{2(\phi 95 - \phi 5)} \qquad \text{(3)}$$

$$\text{Graphic Kurtosis (Kg)} = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)} \qquad \text{(4)}$$

In addition, the data obtained from granulometry was used to generate discriminant binary plot after [20] and subjected to multivariate analysis [21] to underpin the ancient depositional environment as shown in Table 1.

Table 1: Paleoenvironmental discrimination from multivariate statistics [21]

Y1	$-3.5688Mz + 3.7016\sigma_1^2 - 2.0766Ski + 3.1135KG$ *Y1 < -2.7411= Aeolian, Y1 > -2.7411= Beach*
Y2	$15.6534Mz + 65.7091\sigma_1^2 + 18.1071Ski + 18.5043KG$ *Y2 < 65.3650= Beach, Y2 > 65.3650 = Shallow marine*
Y3	$0.2852Mz - 8.7604\sigma_1^2 - 4.8932Ski + 0.0482KG$ *Y3 < -7.419 = Fluvial (deltaic), Y3 > -7.419 = Shallow marine (subtidal)*

4.0 Results and Discussion

Descriptions of the cuttings reveal a dominance of mudstone facies and subordinate sand facies (Fig. 3). The result of the sedimentological analysis is shown in Tables 2-4. In addition, the levels of effervescence observed consequent upon acid treatment vary from zero (0) to three (3) representing absent to strong effervescence levels respectively (Table 4).

4.1 Textural characteristics

4.1.1. Framework characteristics:

The samples are dominantly medium grained sands (98% - 100% framework particles), with average mean and median particle size of 1.87 and 1.93 respectively (Tables 2-5), implying transportation by traction (Fig. 4). In addition, the samples are leptokurtic, negatively (coarse) skewed, moderately well sorted with subangular to subrounded framework.

4.1.2. Textural maturity

The textural maturity of sands is a function of sorting, degree of roundness and amount of clay matrix present (Fig. 5; [22]). Textural maturity improves with better sorting, greater degree of roundness and reduction in clay matrix present. The materials under investigation show up to 2% clay matrix, with moderately well sorted and subangular to subrounded grains. Thus implying that the sands are texturally submature to mature.

Table 2: Sieve analysis result for OB well

OB 1 (1080-1090 FT)					
PHI(ø)	Grain size (mm)	WEIGHT RETAINED (WT)	WT%	CUMULATIVE WT%	% PASSING
-0.75	1.7	0.52	1.04	1.04	98.96
-0.25	1.18	0.57	1.14	2.18	97.82
0.75	0.6	1.22	2.44	4.62	95.38
1.75	0.3	15.38	30.76	35.38	64.62
2.75	0.15	29.80	59.60	94.98	5.02
3.75	0.075	2.39	4.78	99.76	0.24
4	0.063	0.049	0.10	99.86	0.14
PAN		0.071	0.14	100	0
OB 2 (1090-1100 FT)					
PHI(ø)	Grain size (mm)	WEIGHT RETAINED (WT)	WT%	CUMULATIVE WT%	% PASSING
-0.75	1.7	0.72	1.44	1.44	98.56
-0.25	1.18	0.69	1.38	2.82	97.18
0.75	0.6	1.81	3.62	6.44	93.56
1.75	0.3	24.72	49.44	55.88	44.12
2.75	0.15	20.72	41.44	97.32	2.68
3.75	0.075	1.23	2.46	99.78	0.22
4	0.063	0.059	0.12	99.92	0.08
PAN		0.042	0.08	100	0
OB 3 (1100-1110 FT)					
PHI(ø)	Grain size (mm)	WEIGHT RETAINED (WT)	WT%	CUMULATIVE WT %	% PASSING
-0.75	1.7	0.55	1.10	1.10	98.90
-0.25	1.18	0.50	1.00	2.10	97.90
0.75	0.6	0.98	1.96	4.06	95.94
1.75	0.3	16.18	32.36	36.42	63.58
2.75	0.15	27.66	55.32	91.74	8.60
3.75	0.075	4.01	8.02	99.76	0.24
4	0.063	0.069	0.14	99.90	0.10
PAN		0.087	0.17	100	0

Table 3: Sieve analysis result for EG well

EG 1 (230ft)					
PHI(ø)	Grain size (mm)	WEIGHT RETAINED(WT)	WT%	CUMULATIVE WT%	% PASSING
-0.75	1.7	0.63	1.26	1.26	98.74
-0.25	1.18	0.75	1.50	2.76	97.24
0.75	0.6	1.58	3.17	5.93	94.07
1.75	0.3	17.25	34.58	40.51	59.49
2.75	0.15	22.58	45.26	85.77	14.23
3.75	0.075	4.55	9.12	94.89	5.11
4	0.063	1.64	3.28	98.17	1.83
PAN		0.9	1.8	99.97	0.03
EG 2 (250FT)					
PHI(ø)	Grain size (mm)	WEIGHT RETAINED (WT)	WT%	CUMULATIVE WT%	% PASSING
-0.75	1.7	0.75	1.5	1.5	98.5
-0.25	1.18	0.834	1.66	3.16	96.84
0.75	0.6	1.65	3.25	6.41	93.59
1.75	0.3	18.5	37.07	43.48	56.52
2.75	0.15	23.72	47.53	91.01	8.99
3.75	0.075	3.22	6.45	97.46	2.54
4	0.063	0.8	1.6	99.06	0.94
PAN		0.43	0.86	99.92	0.08
EG 3 (330FT)					
PHI(ø)	Grain size (mm)	WEIGHT RETAINED (WT)	WT%	CUMULATIVE WT%	% PASSING
-0.75	1.7	0.54	1.08	1.08	98.92
-0.25	1.18	0.68	1.36	2.44	97.56
0.75	0.6	2.15	4.30	6.71	93.29
1.75	0.3	21.55	43.14	49.88	50.12
2.75	0.15	22.46	44.96	94.84	5.16
3.75	0.075	1.57	3.14	97.98	2.02
4	0.063	0.72	1.44	99.42	0.58
PAN		0.28	0.56	99.98	0.02

4.2 Depositional environment

Sand particles deposited by traction with good textural maturity are typical of arid and near shore environments (Fig. 6). The dominance of quartz and absence of feldspar in the framework, as well as paleoclimatic models which suggest Nigeria was under warm humid climate in the Paleocene Period [23] makes an arid paleoenvironment unlikely. A near shore environment is preferred over an arid environment due to the coarse to near symmetrical Skewness [24] the observed high degree of effervescence from calcite cement which suggests proximity to a marine source. Furthermore, our hypothesis is supported by multivariate analysis (Fig. 7) that suggests a prevalent near shore-shallow marine paleoenvironment, which is congruent with the findings from previous works [4, 5, 6]. Discriminant plot of skewness vs. standard deviation (Fig. 8) suggest some fluvial influence on the samples from EG well, which is interpreted to be due to the more proximal location of the well.

Table 4: Result of Visual Textural Analysis and Effervescence test.

PARAMETERS	OB-1 (1080-1090)	OB-2 (1090-1100)	OB-3 (1100-1110)	EG-1 (230 ft.)	EG-2 (250 ft.)	EG-3 (330 ft.)
SORTING	Moderately wel sorted	Well sorted	Moderately well sorted	moderately sorted	moderately sorted	moderately sorted
PATICLE SIZE	Medium grain	Medium to Fine grain	Fine grain	Medium	Medium	Medium
DEGREE OF ROUNDNESS	Sub-angular to Sub-rounded	Sub-rounded	Sub-rounded to Rounded	sub angular to sub rounded	sub rounded to rounded	sub angular to sub rounded
EFFERVESCENCE	Strong Effervescence	Strong Effervescence	Medium Effervescence	Strong Effervescence	Strong Effervescence	Strong Effervescence

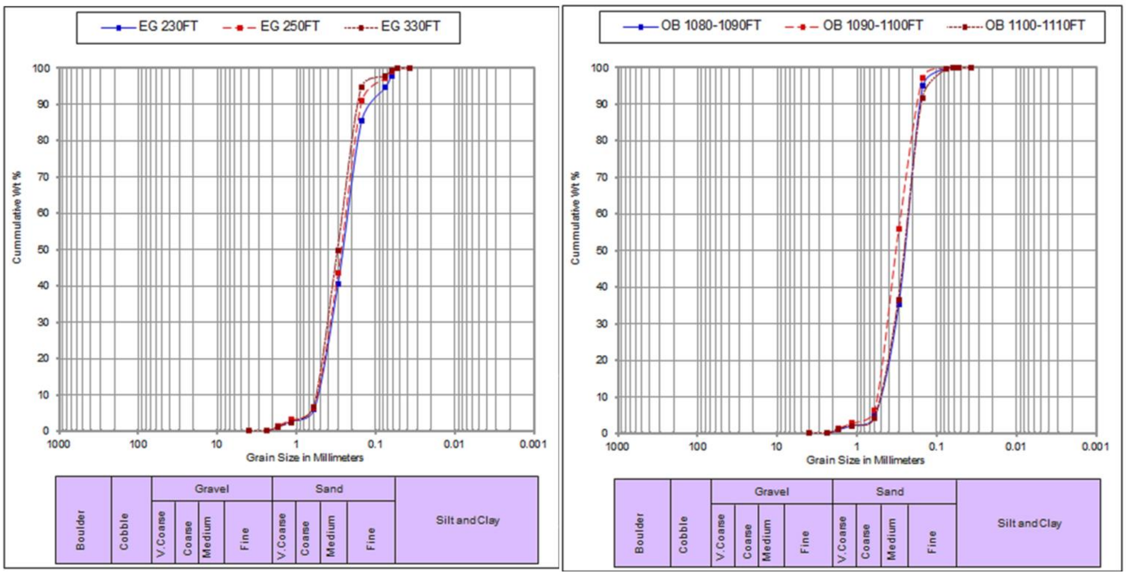

Fig. 4: Plot of Cumulative weight percent against diameter (mm)

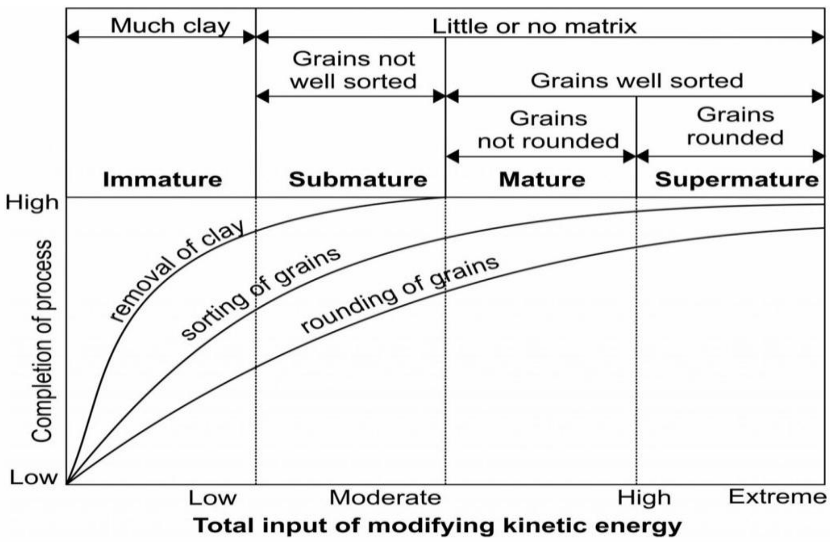

Fig 5: Textural maturity of Sandstones as a function of matrix content, sorting and degree of roundness [22].

Table 5: Result of sieve analysis and multivariate statistics

PARAMETERS	OB-1 (1080-1090)	OB-2 (1090-1100)	OB-3 (1100-1110)	EG-1 (230 ft.)	EG-2 (250 ft.)	EG-3 (330 ft.)
Mean	1.91 (medium sand)	1.73 (medium sand)	2.01 (medium sand)	1.93 (medium sand)	1.91 (medium sand)	1.73 (medium sand)
Med	2 (medium sand)	1.7 (medium sand)	2.05 (medium sand)	2 (medium sand)	2 (medium sand)	1.8 (medium sand)
Standard deviation	0.59 (moderately well sorted)	0.57 (moderately well sorted)	0.6 (moderately well sorted)	0.88 (moderately sorted)	0.76 (moderately sorted)	0.68 (moderately well sorted)
Skewness	-0.2 (coarse skewed)	-0.03 (near symmetrical)	-0.11 (coarse skewed)	0 (near symmetrical)	-0.12 (coarse skewed)	-0.11 (coarse skewed)
Kurtosis	1.02 (leptokurtic)	1.35 (leptokurtic)	1.02 (leptokurtic)	1.31 (leptokurtic)	1.53 (leptokurtic)	1.09 (leptokurtic)
Y1	-1.93679	-0.70585	-2.43652	0.05742	0.334483	-0.84026
Y2	68.0243	72.86686	72.00122	105.3368	93.9903	75.64218
Y3	-1.47696	-2.14099	-1.99308	-6.17048	-3.85435	-2.96662

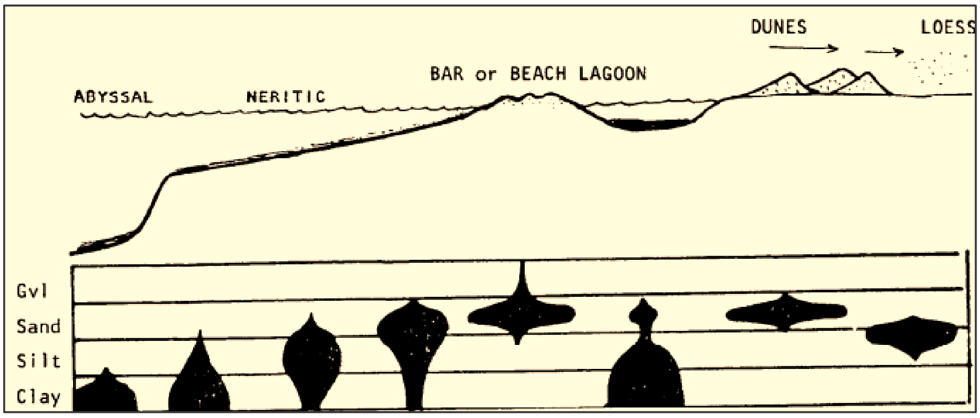

Fig 6: Particle size distribution in various depositional environments [22].

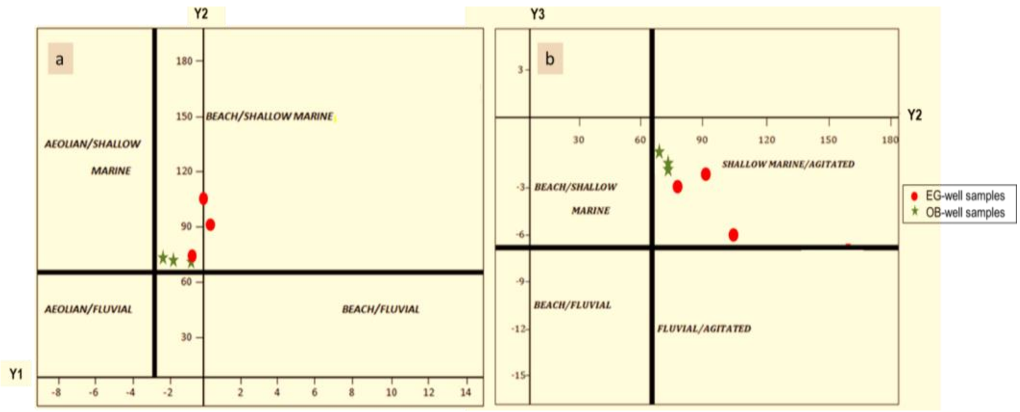

Fig 7: Paleoenvironmental discriminant plot from multivariate analysis [21]

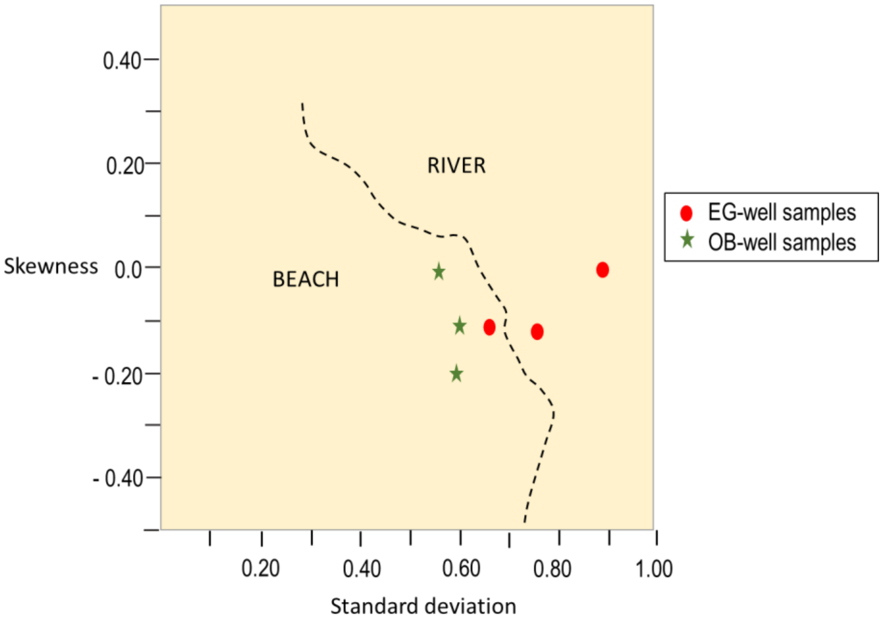

Fig 8: Binary discriminant plot of Skewness vs. Standard deviation [20].

5.0: Conclusion

From the foregoing, this study has revealed that the samples are dominantly well sorted medium grained sands with subangular to subrounded quartzose framework, which are texturally submature to mature. In addition, a near shore shallow marine paleoenvironment, with fluvial influence is hypothesized as the prevalent environment of deposition in this area.

Author Contributions

A. J. EDEGBAI: Project conceptualization, data collection, data analysis and interpretation, manuscript drafting

V. Ehigie: Data collection, data analysis, and manuscript review

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References

[1] Arua, I., 1980. Palaeocene macrofossils from the Imo Shale in Anambra State, Nigeria. J. Min. Geol. 17, 81–84.
[2] Anyanwu, N.P.C., Arua, I., 1990. Ichnofossils from the Imo Formation and their palaeoenvironmnental significance. J. Min. Geol. 26, 1–4
[3] Reijers, T.J.A., Petters, S.W., Nwajide, C.S., 1997. The Niger Delta basin. In: Selley, R.C. (Ed.), African Basins; Sedimentary Basins of the World, vol. 3. Elsevier Sci., B.V., Amsterdam, pp. 151–172.
[4] Nwajide, C.S., 2013. Geology of Nigeria's Sedimentary Basins. CSS Bookshop Ltd., Lagos, 565P.
[5] Ekwenye, O.C., Nicholas, G.J., Collison, M., Nwajide, C.S. and Obi, G.C., 2014. A Paleogeographic Model for the Sandstone members of the Imo Shale, south-eastern Nigeria. Journal of African Earth Sciences, 96, 190-211
[6] Ohwona, O.C., and Okoro, A.U., 2022. Depositional facies analysis of the Ebenebe Sandstone outcropping in Ugwuoba, Umuogbuefi-Ebenebe and Isiagu Area of Southeastern Nigeria. Global scientific Journals, 10 (3), 7-29.

[7] Rouby, d., Nalpas, T., Jermannaud, P., Robin, C., Guillocheau, F., Raillard, S., 2011. Gravity driven deformation controlled by the migration of the delta front: The Plio- Pleistocene of the Eastern Niger Delta . Tectonophysics 513, 54–67.
[8] Tuttle, M.L.W., Charpentier, R.R., Brownfield, M.E., 1999. The Niger Delta Petroleum System: Niger Delta Province, Nigeria Cameroon, and Equatorial Guinea, Africa. Open-File Report 99-50-H, 65p
[9] Chima, K. I., Do Couto, D., Leroux, E., Gardin, S., Hoggmascall, N., Rabineau, M., … Gorini, C. (2019). Seismic stratigraphy and depositional architecture of Neogene intraslope basins, offshore western Niger Delta. Marine and Petroleum Geology. doi:10.1016/j.marpetgeo.2019.06.030 Volume 109, November 2019, Pages 449-468
[10] Cohen, H.A., McClay, K., 1996. Sedimentation and shale tectonics of the northwestern Niger Delta Front. Marine and Petroleum Geology 13 (3), 313–328.
[11] Morgan, R., 2003. Prospectivity in ultradeep water: the case for petroleum generation and migration within the outer parts of the Niger Delta Apron. In: Arthur, M.A., MacGregor, D.S., Cameron, N.R. (Eds.), Petroleum Geology of Africa: New Themes and Developing Technologie. Geological Society Special Publications, London, pp. 151–164.
[12] Evamy, B.D., Haremboure, P., Kamerling, W.A., Knaap, F., Molloy, A. & Rowlands, M.H., 1978. Hydrocarbon habitat of Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin 62 (1), 1–39.
[13] Doust, H., Omatsola, E., 1989. Niger Delta. In: Edwards, J.D., Santogrossi, P.A. (Eds.), Divergent/passive margins, Amer. Assoc. Petrol. Geol. Mem., 48, pp. 2
[14] Short, K.C., Stauble, A.J., 1967. Outline of geology of Niger delta. American Association of Petroleum Geologists Bulletin 15 (5), 761–779.
[15] Avbovbo, A.A., 1978. Geothermal gradients in the southern Nigerian basin. Bull. Canadian Petrol. Geol., 26(2):268-274
[16] Reyment, R.A., 1965. Aspect of the Geology of Nigeria. Ibadan University Press, Nigeria, pp. 145.
[17] Ogbukagu, H.N., 1982. Properties and Beneficiation of argillaceous rocks of southern Nigeria sedimentary Basins. Journal of Mining and Geology, 19 (2), 105-111.
[18] Murat, R.C., 1972. Stratigraphy and paleogeography of the Cretaceous and lower tertiary in southern Nigeria. In: Dessauvagie, T.F.J., Whiteman, A.J. (Eds.), African Geology. University of Ibadan Press, Nigeria, pp. 251–266.
[19] Folk, R. L. and W. C. Ward, 1957, Brazos River bar: A study in the significance of grain-size parameters: J. Sediment. Petrol., 27, 3–26.
[20] Friedman, G. M., 1967, Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands: J. Sediment. Petrol., 37, 327–35
[21] Sahu, B.S., 1964. Depositional mechanisms from the size analysis of clastic sediments. Journal of Sedimentary Petrology 34(1), 73-83
[22] Folk, R. L., 1951, Stages of textural maturity in sedimentary rocks: J. Sediment. Petrol., 21, 127–130
[23] Scotese, C.R., Boucot, A.J, and Chen, X., 2014. Atlas of Phanerozoic Climatic Zones (Mollweide Projection), Volumes 1-6, PALEOMAP Project PaleoAtlas for ArcGIS, PALEOMAP Project, Evanston, IL., 32p.
[24] Duane, D.B., 1964. Significance of Skewness in Recent sediments, Western Pamlico Sound, North Carolina, Journal of Sedimentary Petrology 34 (4). 864-874.