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Geochemistry of Fluvio-Tidal Paleogene Litho-Units of Nsugbe Area, Southeastern Nigeria: Implication for Provenance, Tectonic Setting and Source Area Weathering

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Abstract— Rock chemistry is a function of its origin and history. The fluvio-tidal Paleogene litho-units of Nsugbe area are composed dominantly of fine to coarse, poorly to moderately sorted, subangular to subrounded, quartz-rich sands and sandstones that have a relatively high composition of SiO_2, Al_2O_3 and Fe_2O_3. They are classified into lithicarenite, sublitharenite and quartzarenite with mature polycyclic continental sedimentary rocks that have imprints of plutonic and volcanic rocks from passive and active continental margins source derivation. The CIA and CIW values show that the source area has undergone intense alteration and weathering. This study consolidates and expands the knowledge of provenance and tectonic settings of Paleogene litho-units in Nsugbe area

Index Terms— Provenance; weathering; diagenesis, lithostratigraphy, outcrop, sediment, tectonics.

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1 Introduction

The chemical composition of the rock is a function of its history which is dependent on weathering, transportation and diagenesis [1]. The source area of sediments plays a major role in the mineral constituent and chemical composition [2], [3].

Immobile trace elements such as Y, Sc, Th, Zr, Cr, Hf, Co and rare earth elements (REE) are useful indicators of provenance, tectonic settings and geological processes [4]. Major elements such as SiO_2, Al_2O_3, Fe_2O_3, Na_2O, TiO_2, K_2O, MnO, CaO, and MgO constituent in sediments are good provenance indicator [5], [6].

This study is aimed at integrating major and trace composition in inferring the provenance and source area weathering for Paleogene litho-units in Nsugbe area.

2 Geological Settings

The Nsugbe area cuts across Nkwelle Ezunaka, Awkuzu, Ezinkeje, Nteje, Nsugbe, Nneyi Umuleri, Onitsha prison's and some part of Umunya town in Anambra state (Fig. 1).

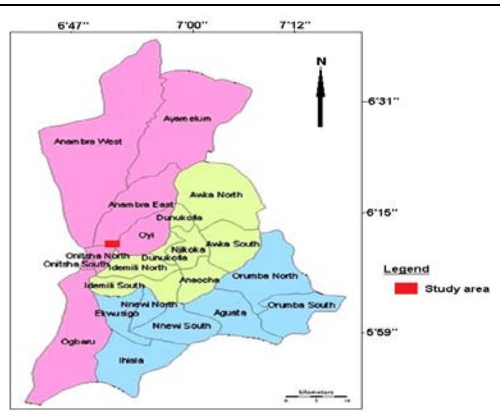

Fig. 1. Map of Anambra State showing study area.

The Eocene sands are part of the outcropping units of the Niger Delta province [7] and they belong to the Ameki group (Table 1).

TABLE 1
Outcropping Units of the Cenozoic Niger Delta [7]

Age	**Lithostratigraphy Units**	
Oligocene-Present	Benin Formation	
Oligocene-Miocene	Ogwashi-Asaba Formation	
Eocene-Early Oligocene	Ameki Group	Nsugbe Formation
		Nanka Formation Ameki Formation
Paleocene-Early Eocene	Imo Formation	

Three lithostratigraphic units which are tidally influenced within the Eocene Nanka Formation namely: (a) lower basal conglomeratic fluvial channel sandstones. (b) middle cross-bedded sandstones unit with a thin mudrock unit. (c) upper ferruginized sandstones unit with estuarine heteroliths intervals [8].

3 Methology

Samples were obtained at site from different outcrop locations. In this study, the lithologic units are analysed based on localities and are uniquely grouped into:

- Sand pockets within sandstones at Nsugbe (SPN
- Sands at Awkuzu-Umunya (SA)
- Ferruginized sandstones at Awkuzu-Umunya (FSA)
- Sands at Nneyi Umuleri (SU)
- Sandstones at Nsugbe (CSN).

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The chemical composition of Eocene litho-units is evaluated using fusion inductively coupled plasma - mass spectrometer. The minerals constituents are evaluated using a polarizing microscope and panalytical X'Pert Pro diffractometer. The chemical index of alteration (CIA) and chemical index of weathering (CIW) is used to infer the extent of weathering in the source area. Various discriminant diagrams are used to infer provenance and sediment history. The sediments are grouped based on the spatial location of core samples obtained.

4 RESULTS AND DISCUSSION

The Paleogene sand grains dominantly have fine to coarse, subangular to subrounded, poorly to moderately sorted grains (Fig. 2).

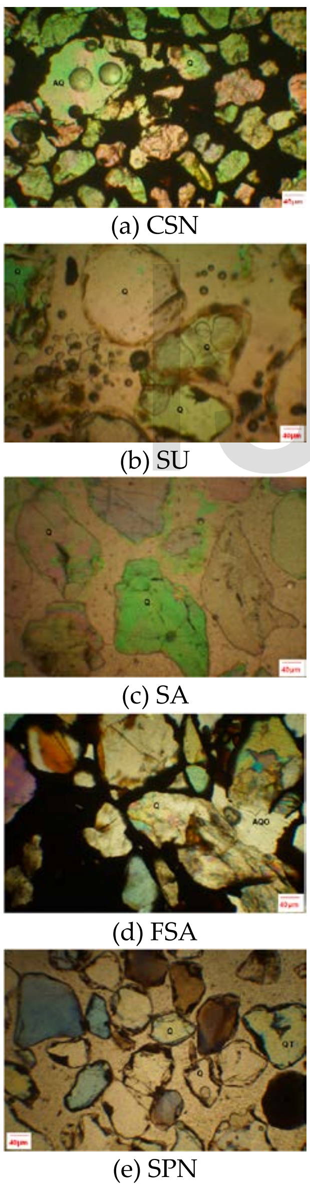

Fig. 2: Photomicrography of Paleogene sands in Nsugbe area.

They show rich quartz (Q) composition (65-95%) which may occur as authigenic quartz overgrowth (AQO).
The quartz grains are undergoing alteration and show the presence of tourmaline (QT) inclusion with opaque (O) minerals probably iron oxides and/or oxyhydroxides, dominantly coating grain edges and micro-fractures.

The sandstones at Nsugbe (CSN) and ferruginized sandstone at Awkuzu (FSA) are well indurated and show quartz-rich composition. CSN is undergoing intense alteration and replacement by opaque minerals probably irons oxides and/or oxyhydroxides (Fig. 2a and Fig. 2d). The opaque minerals fill intergranular pore spaces.

Sands at Nneyi Umuleri (SU), Awkuzu-Umunya (SA) and sand pocket in sandstones at Nsugbe (SSN) are composed dominantly of quartz, kaolinite, k-feldspar and plagioclase. Opaque minerals are found coating grain edges and with patchy presences within the intergranular pore spaces (Fig. 2b, Fig. 2c and Fig. 2e respectively).

Generally, The Paleogene litho-units of Nsugbe area are classified compositional as Lithicarenite, sublitharenite and quartzarenite (Fig. 3).

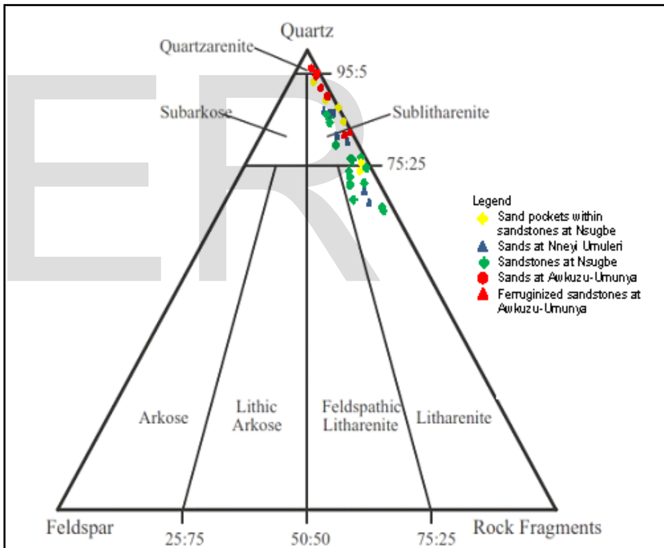

Fig. 3: Classification of Paleogene sands and sandstones within the study area [9].

4.1 Geochemistry

The major element composition of Paleogene sediments of Nsugbe area are measured in percentages and it shows SiO_2, Al_2O_3 and Fe_2O_3 (Total) dominance (Table 2).

The SiO_2 values vary with rock textures, showing values greater than 90% in unconsolidated sands and values greater than 65% for sandstone units.

Generally, the concentration of SiO_2, Na_2O, TiO_2, MnO, CaO and MgO has a positive correlation with Al_2O_3 while Fe_2O_3 is vise versa. They are depleted in CaO but show appreciable presence Al_2O_3 and MgO.

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TABLE 2
MAJOR AND TRACE ELEMENT DISTRIBUTION IN PALEOGENE SANDS AND SANDSTONE UNITS OF NSUGBE AREA.

		SU								SPN					
	UNIT	AZC2	AZB1	TKHC-1	AMD2	AVW2	AJJB-1	AVV2-1	AHB1-1	2-I	3-I	K-1	FRT-1	GGG-2	GH2-1
SiO2	%	96.41	97.28	97.01	96.03	95.37	97.22	96.89	96.11	89.52	92.93	90.84	92.95	93.85	90.58
Al2O3	%	0.87	1.06	0.96	0.98	0.93	1.03	0.99	0.83	4.14	2.05	3.89	1.99	2.01	4.21
Fe2O3 (T)	%	0.69	0.69	0.6	0.51	0.48	0.64	0.69	0.62	1.39	1.73	1.31	1.62	1.45	1.42
MnO	%	0.008	0.008	0.008	0.009	0.007	0.008	0.008	0.007	0.019	0.01	0.015	0.02	0.01	0.017
MgO	%	0.11	0.09	0.08	0.14	0.13	0.1	0.1	0.11	0.19	0.13	0.18	0.11	0.13	0.16
CaO	%	0.2	0.17	0.14	0.19	0.2	0.13	0.18	0.3	0.37	0.26	0.34	0.23	0.24	0.32
Na2O	%	0.07	0.06	0.05	0.07	0.06	0.05	0.06	0.05	0.16	0.09	0.15	0.08	0.1	0.13
K2O	%	0.04	0.03	0.04	0.06	0.04	0.05	0.03	0.05	0.13	0.05	0.11	0.06	0.07	0.14
TiO2	%	0.038	0.036	0.033	0.032	0.029	0.037	0.031	0.029	0.733	0.14	0.729	0.13	0.11	0.75
P2O5	%	0.02	<0.01	<0.01	0.02	0.02	<0.01	<0.01	0.02	0.06	0.03	0.04	0.02	0.03	0.05
LOI	%	0.43	0.51	0.49	0.46	0.44	0.5	0.47	0.45	1.85	1.13	1.93	1.25	1.11	1.82
Total	%	98.88	99.94	99.411	98.501	97.706	99.765	99.449	98.576	98.562	98.55	99.534	98.46	99.11	99.597
Na2O/Al2O3		0.080	0.057	0.052	0.071	0.065	0.049	0.061	0.060	0.039	0.044	0.039	0.040	0.050	0.031
SiO2/Al2O3		110.816	91.774	101.052	97.990	102.548	94.388	97.869	115.795	21.623	45.332	23.352	46.709	46.692	21.515
k2O/Al2O3		0.046	0.028	0.042	0.061	0.043	0.049	0.030	0.060	0.031	0.024	0.028	0.030	0.035	0.033
TiO2/Al2O3		0.044	0.034	0.034	0.033	0.031	0.036	0.031	0.035	0.177	0.068	0.187	0.065	0.055	0.178
Fe2O3 (T)/Al2O3		0.793	0.651	0.625	0.520	0.516	0.621	0.697	0.747	0.336	0.844	0.337	0.814	0.721	0.337
CaO/Al2O3		0.230	0.160	0.146	0.194	0.215	0.126	0.182	0.361	0.089	0.127	0.087	0.116	0.119	0.076
MgO/Al2O3		0.126	0.085	0.083	0.143	0.140	0.097	0.101	0.133	0.046	0.063	0.046	0.055	0.065	0.038
Log SiO2/Al2O3		2.045	1.963	2.005	1.991	2.011	1.975	1.991	2.064	1.335	1.656	1.368	1.669	1.669	1.333
Log Fe2O3/K2O		1.237	1.362	1.176	0.929	1.079	1.107	1.362	1.093	1.029	1.539	1.076	1.431	1.316	1.006
CIW	%	76.316	82.171	83.478	79.032	78.151	85.124	80.488	70.339	88.651	85.417	88.813	86.522	85.532	90.343
CIA	%	73.729	80.303	80.672	75.385	75.610	81.746	78.571	67.480	86.250	83.673	86.637	84.322	83.058	87.708

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TABLE 2 (CONTINUED)

		SU					FSA		CSN						
	UNIT	MCD	CDC	WVH	MTJ-1	VBND-1	AZXSA	AZXP	AAA	NLSA	AAC	NLSB	NSHCB	PMXA	PMXC
SiO2	%	91.88	93.64	92.01	93.67	92.99	74.08	74.96	59.74	65.73	62.65	64.66	63.31	70.93	69.89
Al2O3	%	2.38	2.13	2.36	2.15	2.22	0.63	0.58	1.29	1.14	1.16	1.14	1.23	0.89	0.97
Fe2O3 (T)	%	3.51	2.08	3.49	2.11	2.08	20.22	19.95	32.8	28.65	29.7	28.02	30.7	23.42	24.33
MnO	%	0.01	0.009	0.011	0.008	0.01	0.01	0.01	0.017	0.015	0.018	0.015	0.017	0.022	0.021
MgO	%	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.03	0.03	0.04	0.03	0.03	0.04	0.04
CaO	%	0.08	0.1	0.07	0.08	0.07	0.13	0.15	0.08	0.04	0.07	0.04	0.07	0.09	0.08
Na2O	%	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04	0.03	0.04	0.03	0.03	0.03	0.04
K2O	%	0.29	0.29	0.28	0.27	0.29	0.02	0.02	0.34	0.03	0.03	0.03	0.04	0.02	0.03
TiO2	%	0.083	0.067	0.085	0.064	0.079	0.026	0.021	0.137	0.036	0.133	0.037	0.039	0.059	0.053
P2O5	%	0.05	0.05	0.06	0.05	0.06	0.76	0.69	1.18	0.05	1.15	0.06	0.08	0.03	0.04
LOI	%	1.4	1.02	1.38	1.14	1.11	3.49	3.26	4.76	3.67	4.69	3.62	3.51	3.68	3.57
Total	%	99.773	99.476	99.836	99.632	98.999	99.466	99.741	100.414	98.421	99.961	96.682	99.056	99.211	99.064
Na2O/Al2O3		0.017	0.019	0.017	0.019	0.018	0.063	0.086	0.031	0.026	0.034	0.026	0.024	0.034	0.041
SiO2/Al2O3		38.605	43.962	38.987	43.567	41.887	117.587	129.241	46.310	57.658	54.009	56.719	51.472	79.697	72.052
k2O/Al2O3		0.122	0.136	0.119	0.126	0.131	0.032	0.034	0.264	0.026	0.026	0.026	0.033	0.022	0.031
TiO2/Al2O3		0.035	0.031	0.036	0.030	0.036	0.041	0.036	0.106	0.032	0.115	0.032	0.032	0.066	0.055
Fe2O3 (T)/Al2O3		1.475	0.977	1.479	0.981	0.937	32.095	34.397	25.426	25.132	25.603	24.579	24.959	26.315	25.082
CaO/Al2O3		0.034	0.047	0.030	0.037	0.032	0.206	0.259	0.062	0.035	0.060	0.035	0.057	0.101	0.082
MgO/Al2O3		0.021	0.023	0.021	0.023	0.023	0.095	0.086	0.023	0.026	0.034	0.026	0.024	0.045	0.041
Log SiO2/Al2O3		1.587	1.643	1.591	1.639	1.622	2.070	2.111	1.666	1.761	1.732	1.754	1.712	1.901	1.858
Log Fe2O3/K2O		1.083	0.856	1.096	0.893	0.856	3.005	2.999	1.984	2.980	2.996	2.970	2.885	3.069	2.909
CIW	%	95.200	93.833	95.547	94.714	95.279	78.750	74.359	91.489	94.215	91.339	94.215	92.481	88.119	88.991
CIA	%	85.305	83.203	85.818	84.646	84.733	76.829	72.500	73.714	91.935	89.231	91.935	89.781	86.408	86.607

TABLE 2 (CONTINUED)

		SU								SPN					
	UNIT	AZC2	AZB1	TKHC-1	AMD2	AVW2	AJJB-1	AVV2-1	AHB1-1	2-I	3-I	K-1	FRT-1	GGG-2	GH2-1
Sc	ppm	<1	<1	<1	<1	<1	<1	<1	<1	4	2	3	2	2	4
Be	ppm	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
V	ppm	9	8	8	8	9	7	8	9	41	32	37	30	34	40
Cr	ppm	<20	<20	<20	<20	<20	<20	<20	<20	30	<20	32	<20	<20	29
Co	ppm	1	1	1	1	1	1	1	1	2	1	2	1	1	1
Ni	ppm	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Cu	ppm	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Zn	ppm	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Ga	ppm	1	2	2	1	1	1	2	2	7	3	5	3	3	7
Ge	ppm	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
As	ppm	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Rb	ppm	<2	<2	<2	<2	<2	<2	<2	<2	4	<2	3	<2	<2	4
Sr	ppm	10	8	7	9	9	8	10	9	66	27	57	26	24	64
Y	ppm	7	7	7	6	6	7	6	5	21	7	23	9	7	19
Zr	ppm	63	59	59	64	62	63	60	61	139	165	110	121	159	121
Nb	ppm	<1	1	1	<1	<1	<1	1	<1	14	2	15	6	3	11
Mo	ppm	<2	<2	<2	<2	<2	<2	<2	<2	<2	3	<2	<2	3	<2
Ag	ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3.3	<0.5	2.9	<0.5	<0.5	3.1
In	ppm	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sn	ppm	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	1	<1	<1	1
Sb	ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cs	ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ba	ppm	21	20	20	22	22	20	20	21	150	77	135	75	68	143
Hf	ppm	1.4	1.4	1.4	1.2	1.3	1.4	1.3	1.1	32.8	3.9	27.9	3.5	3.8	29.3
Ta	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.6	0.2	1.4	0.3	0.3	1.4
W	ppm	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pb	ppm	<5	<5	<5	<5	<5	<5	<5	<5	12	6	11	5	7	12
Bi	ppm	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Th	ppm	1.5	1.5	1.5	1.4	1.5	1.4	1.5	1.5	15.9	2.8	13.7	3.1	2.9	14.2
U	ppm	0.5	0.4	0.4	0.5	0.5	0.4	0.4	0.5	2.9	0.7	3	0.8	0.7	2.8
Th/U		3.000	3.750	3.750	2.800	3.000	3.500	3.750	3.000	5.483	4.000	4.567	3.875	4.143	5.071
Zr/Th		42.000	39.333	39.333	45.714	41.333	45.000	40.000	40.667	87.547	58.929	80.657	39.032	54.828	85.423
Th/Co		1.500	1.500	1.500	1.400	1.500	1.400	1.500	1.500	7.950	2.800	6.850	3.100	2.900	14.200

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TABLE 2 (CONTINUED)

		SU					FSA		CSN						
	UNIT	MCD	CDC	WVH	MTJ-1	VBND-1	AZXSA	AZXP	AAA	NLSA	AAC	NLSB	NSHCB	PMXA	PMXC
Sc	ppm	1	<1	1	<1	<1	7	7	2	9	3	9	8	3	5
Be	ppm	1	<1	1	<1	<1	8	7	6	<1	5	<1	<1	4	4
V	ppm	15	13	12	12	13	56	53	38	20	36	21	21	30	29
Cr	ppm	<20	<20	<20	<20	<20	250	247	20	20	20	20	21	<20	<20
Co	ppm	2	2	2	3	2	2	1	6	1	5	1	1	3	3
Ni	ppm	<20	<20	<20	<20	<20	<20	<20	30	<20	30	<20	30	<20	<20
Cu	ppm	<10	<10	<10	<10	<10	10	11	<10	20	<10	20	<10	<10	<10
Zn	ppm	<30	<30	<30	<30	<30	90	88	90	40	79	40	70	100	97
Ga	ppm	3	3	3	2	3	4	3	3	1	3	1	1	2	2
Ge	ppm	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	2	<1	<1	<1
As	ppm	<5	<5	<5	<5	<5	15	13	16	<5	14	<5	12	<5	<5
Rb	ppm	9	8	8	9	9	<2	<2	9	<2	7	<2	6	<2	<2
Sr	ppm	20	23	21	22	24	6	6	53	4	55	4	53	6	9
Y	ppm	9	9	8	7	8	<2	<2	3	<2	4	<2	3	5	5
Zr	ppm	72	81	70	79	71	46	50	146	49	138	45	141	54	55
Nb	ppm	2	2	2	2	2	<1	<1	2	<1	2	<1	1	1	1
Mo	ppm	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ag	ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
In	ppm	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sn	ppm	<1	<1	<1	<1	<1	<1	<1	1	<1	1	<1	1	<1	<1
Sb	ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cs	ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ba	ppm	85	87	83	84	80	39	34	227	22	221	25	209	18	20
Hf	ppm	1.9	2	1.8	1.9	1.6	1	1	3.3	1.2	3.2	1.4	3.1	1.3	1.2
Ta	ppm	0.5	0.1	0.5	0.1	0.5	<0.1	<0.1	0.2	<0.1	0.2	<0.1	0.2	<0.1	<0.1
W	ppm	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pb	ppm	8	6	7	5	6	10	11	6	6	6	6	6	<5	<5
Bi	ppm	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	0.4	0.4
Th	ppm	2.2	1.9	2.1	2.2	2	1.4	1.4	3.8	3.3	3.5	3.2	3.4	1.6	1.8
U	ppm	0.9	0.8	0.7	0.8	0.8	6.1	5.9	1.9	3	1.7	2.9	1.6	0.9	1
Th/U		2.444	2.375	3.000	2.750	2.500	0.230	0.237	2.000	1.100	2.059	1.103	2.125	1.778	1.800
Zr/Th		32.727	42.632	33.333	35.909	35.500	32.857	35.714	38.421	14.848	39.429	14.063	41.471	33.750	30.556
Th/Co		1.100	0.950	1.050	0.733	1.000	0.700	1.400	0.633	3.300	0.700	3.200	3.400	0.533	0.600

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Weathering is the probable cause of the low values of MgO, CaO, Na_2O and K_2O, while a decrease in silica is caused dominantly by leaching of clay minerals since quartz is less soluble. The indurated sands have relatively higher Fe_2O_3(total) values and the Fe concentration in sediment is most likely a product of weathering. These sands are relatively more mature towards south and with increasing paleo-marine influence in sandstones at Nsugbe town. The trace element composition is measured in part per million (ppm) and it shows a relatively high abundance of Zr which has a positive correlation with Th and U (Table 2).

Sc shows a negative correlation with Th. SiO_2 is the most abundant element in Paleogene litho-units of Nsugbe area and it shows a positive correlation with Zr and Hf whereas V and Sr show a negative correlation with SiO_2. The low Sr content in ferruginized sandstones is due to intense replacement of minerals with iron oxides and/or oxyhydroxides.

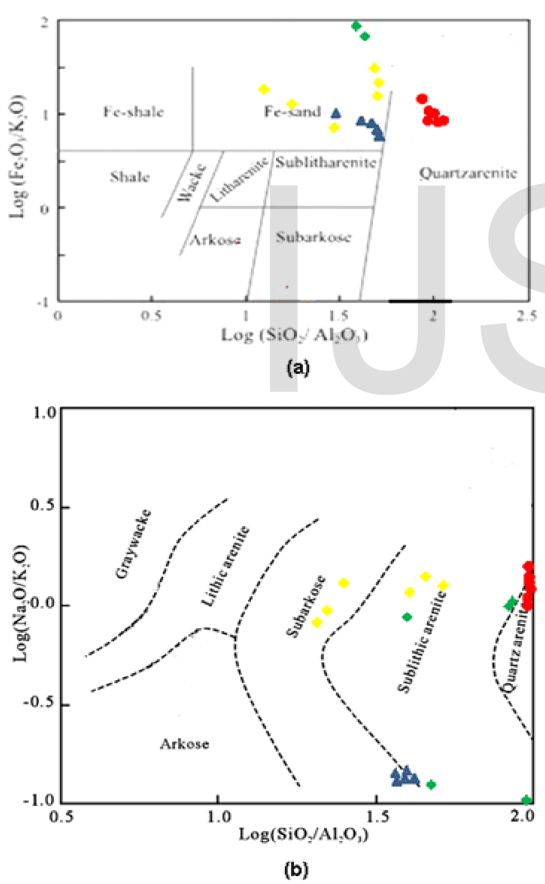

Fig. 3: Sand classification (a) Using $\log(SiO_2/Al_2O_3)$ versus $\log(Fe_2O_3/K_2O)$ diagram [10] (b) Using $\log(SiO_2/Al_2O_3)$ versus $\log(Na_2O/K_2O)$ Diagram [6].

4.2 Tectonic Setting

Using K_2O/Na_2O versus SiO_2 diagram [11], the Paleogene litho-units are derived dominantly from passive margins with imprints of active continental margin sediment sources derivation (Fig. 5).

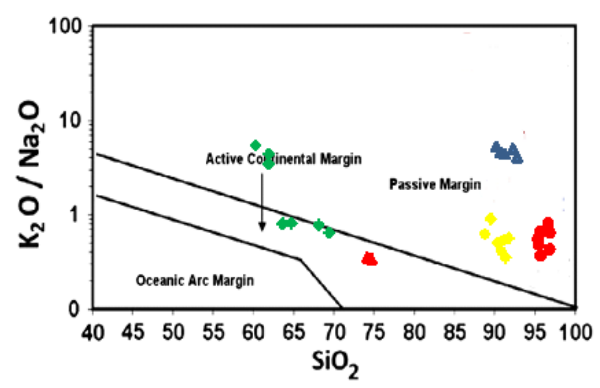

Fig. 5. SiO_2 versus K_2O/Na_2O Diagram [11].

The high K_2O/Na_2O and SiO_2/Al_2O_3 suggest that the Paleogene lithologic units are derived from poly-recycled older rocks and stable continental area. Th/U ratio of 3.5 and 4.0 is typical of crustal rocks [12]. The Th/U ratio of Paleogene lithologic units of Nsugbe area is less than 6. The Th/U value of sands at Awkuzu-Umunya and Umuleri are within 2 to 4 while sandstones at Nsugbe and Onitsha prisons are 1 to 3. In addition, the ferruginized sandstones Th/U values are less than 0.5 while sand pockets within sandstone at Nsugbe values are within 4 to 6.

4.3 Provenance

The Paleogene litho-units of Nsugbe area show significantly low percentage or absence of feldspar which indicates that sediments are texturally mature and are probably from recycled sediment sources. The abundance of monocrystalline quartz over polycrystalline quartz indicated distant sources. Using ternary plots [13], the Paleogene lithologic units are derived from recycled orogenic sources with sediments of craton interior, quartzose and transitional recycled source derivations (Figure 6).

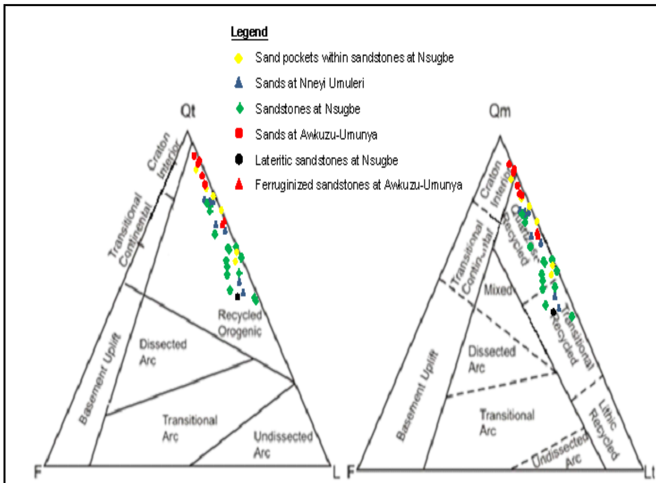

Fig. 6. QtFL and QmFLt Ternary Diagram [13] for sands and sandstones samples in the study area.

The high SiO2 content reflects derivation from stable cratons source enriched with granitic source rock. Zr, Hf, Y and Th are significantly present in trace quantities and these trace elements are as enriched in felsic rather than mafic sources [14].

Generally, they are dominantly mature polycyclic continental sedimentary rocks with imprints of acid plutonic and volcanic rock derivation (Fig. 7).

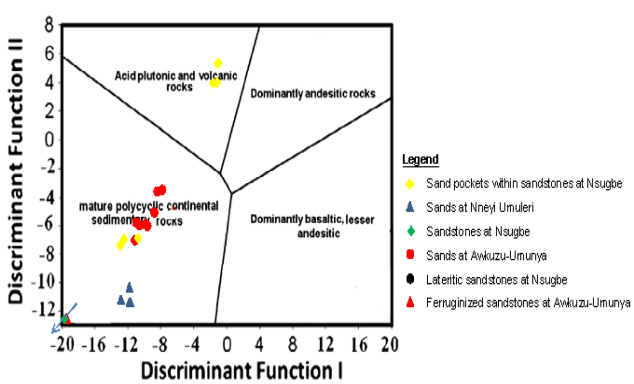

Fig. 7. Major element provenance discriminant plot [5].

4.4 Source Area Weathering

Th/U ratio higher than 4.0 indicates weathering in source area and sediment recycling [12]. The CIA and CIW values are excellent indices for evaluating the degree of weathering [15].

Generally, the Paleogene sands and sandstones at Nsugbe area show CIA values that are greater than 70% with an average of 79.8±5.25% and CIW values are greater than 75% with an average of 85.35±8.29%. These CIA values imply that the source area of sediments has undergone alteration which may have resulted in the formation of clay minerals. The CIW values indicate intense weathering within source area. The rate of weathering is a function of the paleoclimatic conditions which is dominantly humid (Figure 8).

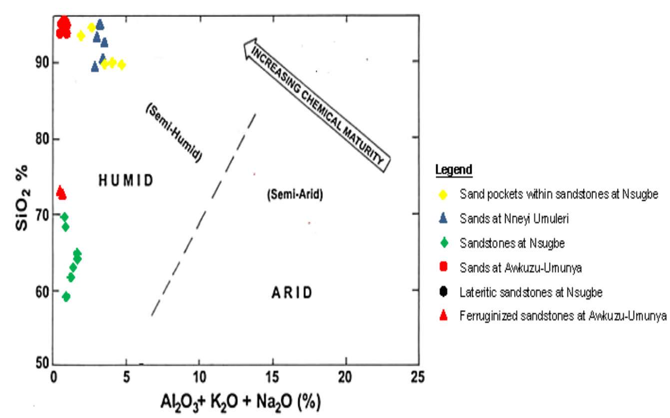

Fig. 8. Chemical maturity and paleoclimatic environment of Eocene sands within study area [16].

5 CONCLUSION

The Paleogene lithogic units of Nsugbe area are composed of dominantly sands and sandstones which have poorly to moderately quartz-rich grains and they are classified as lithicarenite, sublitharenite and quartzarenite. These units are high in SiO_2, Al_2O_3 and Fe_2O_3 (Total) and show the varying composition of Zr in trace quantities. They are derived from dominantly from passive margins and active continental sources. The sediments are inferred to be polycyclic continental sedimentary rocks with imprints of plutonic and volcanic derivations. The source area is inferred to have undergone intense alteration and weathering.

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