Petrographic Studies, Heavy Mineral Analysis and Pebble Morphogenesis; Implications for Sedimentary Processes of Southern Bida Basin, Nigeria

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Abstract: **The sandstone and conglomeratic sandstone facies of Lokoja and Patti Formation, Southern Bida Basin were analysed for their mineralogical compositions and pebble morphogenesis. The identified framework grains include the dominant quartz grains, feldspars, mica and rock fragments while heavy minerals include Zircon, Topaz, Tourmaline, Staurolite, Sphene, Rutile and Olivene. The heavy minerals were used as indicators of sources of sediments; Zircon and Tourmaline suggest igneous and low grade metamorphic rocks where as Staurolite and Rutile show high grade metamorphic rocks. The angular to sub-angular shapes of the heavy minerals and sub-angular shapes of quartz grains respectively indicate textural immaturity of the sediments. This is associated with absence or low degree of physical weathering and abrasion due to short distance of sediment transport and it implies the prevalence of chemical weathering of the source rocks. The grain to grain contacts among quartz grains, the occurrence of overgrowths and iron oxide cements are consequences of post depositional changes of the sediments. Interpretation of pebble sizes, sphericity and oblate-prolate index provided information about the paleoenvironments.**

Keywords: **Heavy Minerals, Pebble Morphogenesis, Bida Basin, Sedimentary Processes, Paleoenvironments.**

I. INTRODUCTION

Bida Basin is an inland sedimentary basin in the central part of Nigeria. It trends in NW-SE, and perpendicular to the main axis of Benue trough. It is adjacent to the Anambra Basin at the east and Sokoto Basin at the North West. The sediment fills of the basin are upper Cretaceous clastic sequence of sandstones, shales, siltstones and ironstones. The basin is characterized laterally by different facies, so it's geographically described as northern and southern Bida Basin. Several geological studies of the basin have been carried out by researchers and their reports published.[1]discussed the geologic development of Southern Bida Basin. [2] carried out facies analysis of Bida Sandstone. [3] focused on grain size distribution and particle morphogenesis of Bida Basin. [4] produced a report on the upper Cretaceous sequences in the southern Bida Basin; they ascertained that the basin and in particular Patti Formation, was deposited by fluvial environment and periodic influence of marginal marine environment during transgression. [5]researched on the heavy mineral distributions in southern Bida Basin and concluded that the sediments were derived from igneous and metamorphic rocks by chemical weathering, and they were deposited close to the source.

In this work, we interpreted the compositions and textures of siliclastic sedimentary rocks, Lokoja and Patti Formation, Southern Bida Basin, located at Okunmi$007^0 51^{'}$ 43.0$^{''}$N and $006^0 45^{'}$ 36.4''E, Agbaja road 007^0 56' 55.4$^{''}$N and $006^0 39^{'}$38.1$^{''}$E and Yewuti Sabo$008^0 18^1$50.0''Nand $006^0 57^1$50.0''E even as they proceeded from the sources to burial and underwent post depositional modifications. These techniques have been used to elucidate the formation of sedimentary rocks, [6] and [7].

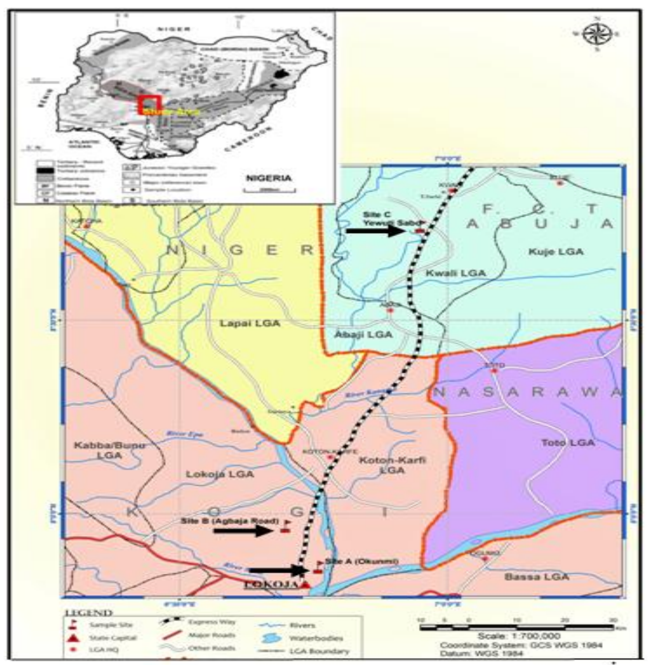

Fig 1: Map of the study area

II.GEOLOGICAL SETTING AND STRATIGRAPHY

Whereas there is a growing consensus [8] that Bida Basin originated from a rift sequel to the separation of South American and African plates, divergent opinions about the processes had been reported. [9] and [10] suggested rift-bounded tensional structure caused by faulting associated with the Benue Trough and the separation of African and Brazilian plates. [1]explained that a wrench fault tectonic event of sinistral movements along the bounding chain and charcot fracture zones of the Benue Trough resulted to horst and graben. The graben is typical of Bida Basin.

The sediment fills of the basin took place in the Campanian to Maastrichtian. The oldest stratigraphic unit in the southern Bida Basin, the Lokoja Formation lies unconformably on the Basement Complex. The lithofacies include the basal conglomerates, massive to cross stratified, fine to very coarse grained, poorly sorted sandstone, siltstones and claystones. The environment of deposition of this formation has been ascertained to be continental, [4] and [11]. Succeeding the Lokoja Formation is the Patti Formation. It is about 70-100m thick and consists of sand stones, siltstones, claystones and shale. The formation is predominantly fine grained. Comparatively, they are miner logically and texturally more mature than Lokoja Formation, [12]. The Patti Formation was deposited by marine and continental environments, [4]. The youngest unit of the stratigraphic sequence of Southern Bida Basin is Agbaja ironstone. It is about 20m thick, and comprises the oolitic, concretional and massive ironstones.

III. METHODS OF STUDY

Twenty four samples were selected from the three studied areas for petrographic studies. In addition, ten samples were chosen from one area, Yewuti Sabo section to be investigated for the heavy mineral contents. Also, one hundred pebbles were picked from alithologic unit of the same section for morphometric research. Thin section microscopy was carried out with the aid of petrographic microscopes. The slides were mounted on the microscopes and viewed in order to identify, describe and quantify the majorand accessory framework minerals. Also mineral cements were identified and described. Furthermore, slides containing heavy minerals were placed on microscopes and viewed to identify, describe and quantify the non-opaque heavy mineral components in the sandstones. The mineralogical maturity of the sediments was investigated using the Zircon-Tourmaline-Rutile index formula after [5] and [13]; ZRT index=(Zircon+Tourmaline+Rutile X 100)/Non-opaque.

Grain shapes of quartz and heavy minerals were observed in order to infer the textural characteristics. Pebble morphometry measurements were carried out using venire caliper. The long (L), intermediate (I) and short (S) axes were measured and used to derive morphometric quantities such as flatness ratio (S/L) and elongation ratio (I/L) after [14]. In addition, maximum projection sphericity index (M.P.S.I) and oblate-prolate index (OPI) were derived after [15] and [16] respectively. Roundness of the pebbles was visually estimated.

IV. RESULTS

Non-opaque heavy minerals

The proportion of non-opaque heavy minerals is presented intable1. They are dominated by Zircon, Topaz, Tourmaline and Staurolite. The percentage composition of Zircon is highest in six samples with high occurrence in two samples and absent in one sample. Topaz appears highest in one of the samples, and has moderate to high proportions in the other eight samples. Tourmaline and Staurolite are present with low to high proportions in all the samples. On the other hand, Sphene, Rutile and Olivine have lower proportion of the heavy minerals. Sphene is present in low to moderate proportions in eight samples. Likewise, the proportion of Rutile is low to moderate in six samples. Olivine is almost absent in the samples but for two, in very low quantity. Consequence of the heavy mineral representation per sample, the overall percentage proportion of the heavy minerals of the studied area was deduced. It is dominated in the order from the highest to the least as follows: Zircon (33.3%), Topaz (18.0%), Tourmaline (16.8%), Staurolite (14.8%), Sphene (10.4%), Rutile (6.0%) and Olivine 0.7%.

Pebble Morphometry

The measured long (L), intermediate (I) and short (S) axes of the pebbles and the derived morphometric quantities are presented in table 2. The flatness ratio (S/L) ranges from 0.10to 1.46, the elongation ratio (I/L)ranges from 0.37 to 0.99, maximum projection sphericity index (M.P.S.I.) varies from 0.17 to 0.97 and oblate-prolate indexvaries from -42.5 to 13.25. Estimated values of roundness are between 10 to 60 %.

Petrographic analysis

The identified framework minerals and cements are provided in tables 3 and 4.

Quartz:Quartz (plates 1 and 2) are the dominant minerals in the sandstones of Lokoja Formation;at Okunmi, it varies from 80.39% to 87.25% in the samples. There is more monocrystalline quartz than polycrystalline quartz. Monocrystalline quartz varies from 78.43% to 84.24% while polycrystalline quartz varies from 1.28% to 3.92%. The percentage composition of quartz grains in Agbajaroad section, Patti Formation varies from 98.84% to 100%. Monocrystalline quartz varies from 98.27% to 99.05% while polycrystalline quartz varies from 0.58% to 1.00%. At Yewuti Sabo, monocrystalline quartz was identified in the samples. The percentage composition varies from 80-95%.

Each of the samples has different grain sizes, which range from fine to gravel-size grains. The cluster of different grain sizes in the thin sections indicate that the rock sediments of Okunmi, Yewuti Sabo and lower lithologic units of Agbajaroad sections are poorly sorted, while the upper lithologic unit of Agbaja section is moderately sorted. The grain shapes of the samples from Okunmi, Agbaja road, and Yewuti Sabo sections are sub-angular. The grains of the upper lithologic unit of Agbajaroad section have loosely packed fabrics and some of the grains are floating in the matrix. The grains of rock samples from Okunmi and Yewuti Sabo are closely packed, leading to grain to grain contacts like sutured contacts.

Feldspar: Feldspar (plates 3 and 4) are moderately represented in the sandstones from Okunmi section, they vary from 10.91 to 17.64%. Plagioclase feldspar is the most dominant of the three types of the feldspars. Others are microcline and orthoclase. The latter is the least encountered. There is no occurrence of feldspar in sandstones from Agbajaroad section. At Yewuti Sabo, feldspars occur in few samples with percentage composition of 2 to 5%. Three types of feldspars were recognised. They were microline, orthoclase and plagioclase.

Rock Fragments: Rock fragments(plate5) are minor components in the investigated sandstones. They vary from 0.97% to 3.01% in the sandstones from Okunmi section and 0.74% to 1.16% in the sandstones from Agbajaroad section. The rock fragments do not have mineral orientation. The proportion of rock fragments in the samples from Yewuti Sabo varies from 0.85 to 3.50%

Accessory Minerals: Few flakes of muscovites (plates 6) were identified as one of the minor components of the sandstones samples from Okunmisections and in some samples from Yewuti Sabo. Mica is not encountered in the samples from Agbajaroad section.

Cement Materials: The cement materials identified in the sandstones are not generally developed. Iron oxide cements were seen as grain coating material round the edges of quartz grains in all the sandstones samples from Okunmi, Agbajaroad and Yewuti Sabo. Also, overgrowths are seen around some detrital quartz grains in the samples, (plates 1)

Table 1: Heavy Mineral Composition of Patti Formation At Yewuti Sabo.

Sample no	Sphene	Zircon	Staurolite	Topaz	Tourmaline	Oliven e	Rutile	Total Non opaque	Z+T+R	ZTR% INDEX
10P	-	31	10	6	9	-	4	60	44	73
10Q	7	-	4	16	4	-	7	38	11	29
10L^{1}	4	26	6	9	18	-	2	65	46	71
10L	5	27	12	16	15	-	13	88	55	63
10H	8	25	12	11	17	-	-	73	42	58
10E	8	11	26	21	16	3	-	85	27	32
10D	2	28	4	8	6	-	6	54	40	74
10C	7	26	5	7	7	-	2	54	35	65
10A	18	15	5	8	3	1	-	50	18	36
Total	59	189	84	102	95	4	34	567	318	56.1
%	10.4	33.3	14.8	18.0	16.8	0.7	6.0	Individual mineral percentage abundance		

Table 2: Pebble Morphometric Data Of Conglomeratic Sandstone of Yewuti Sabo, Patti Formation

SN	S (cm)	I (cm)	L (cm)	S/L	I/L	M.P.S.I	OP	Roundness	Mineral Fragment
1	2.83	3.12	6.01	0.47	0.52	0.75	8.68	30	Quartz
2	1.12	1.30	2.35	0.44	0.55	0.74	8.43	40	Quartz
3	0.76	1.62	2.22	0.34	0.73	0.54	-2.58	10	Quartz
4	1.10	1.23	2.00	0.55	0.62	0.79	6.46	50	Quartz
5	1.21	1.52	2.02	0.60	0.75	0.78	1.96	40	Quartz
6	1.13	1.90	2.40	0.47	0.79	0.66	2.26	20	Quartz
7	1.20	1.50	2.65	0.45	0.57	0.71	6.42	30	Quartz
8	1.25	1.60	2.40	0.52	0.67	0.75	3.76	60	Quartz
9	0.90	1.70	2.50	0.36	0.68	0.58	0.00	20	Quartz
10	1.30	1.35	2.00	0.65	0.68	0.86	6.59	20	Quartz
11	0.93	1.17	2.00	0.47	0.59	0.72	5.93	30	Quartz
12	0.73	1.54	2.10	0.35	0.75	0.55	-2.62	10	Quartz
13	1.40	1.80	3.03	0.46	0.59	0.71	5.51	20	Quartz
14	1.10	1.80	2.44	0.45	0.74	0.65	-4.97	25	Quartz
15	1.13	1.40	2.51	0.45	0.56	0.71	6.76	30	Quartz

16	1.02	1.40	2.56	0.40	0.55	0.66	6.36	25	Quartz
17	1.00	1.44	1.50	0.67	0.96	0.77	5.51	30	Quartz
18	0.92	1.50	1.93	0.48	0.78	0.66	-1.56	25	Quartz
19	1.20	1.20	2.14	0.56	0.56	0.82	8.92	30	Quartz
20	1.13	1.60	1.90	0.59	0.84	0.75	-1.86	30	Quartz
21	1.40	1.70	2.40	0.58	0.71	0.78	3.43	30	Quartz
22	1.10	1.20	2.40	0.46	0.50	0.75	9.23	40	Quartz
23	0.80	1.40	3.00	0.27	0.47	0.53	8.52	25	Quartz
24	0.65	1.70	2.30	0.28	0.74	0.48	-4.83	10	Quartz
25	0.85	1.40	2.10	0.40	0.67	0.6	1.48	30	Quartz
26	0.90	1.50	1.91	0.47	0.79	0.66	1.99	30	Quartz
27	1.13	1.40	1.93	0.59	0.73	0.78	2.78	40	Quartz
28	0.80	1.23	2.75	0.29	0.45	0.57	9.61	20	Quartz
29	1.02	1.50	1.66	0.69	0.90	0.75	-4.07	30	Quartz
30	1.13	1.74	1.90	0.59	0.92	0.73	-4.91	30	Quartz
31	0.90	1.57	1.71	0.53	0.92	0.67	-6.22	20	Quartz
32	0.80	0.93	2.50	0.32	0.37	0.65	13.23	10	Quartz
33	0.80	1.34	1.75	0.46	0.77	0.65	-1.50	20	Quartz
34	0.70	1.23	1.73	0.40	0.71	0.61	-3.60	20	Quartz
35	1.12	1.50	2.00	0.56	0.75	0.75	1.22	25	Quartz
36	0.90	1.34	1.62	0.56	0.81	0.72	-1.50	40	Quartz
37	0.95	1.30	1.82	0.52	0.98	0.72	1.87	20	Quartz
38	1.10	1.60	1.90	0.58	0.84	0.74	-2.16	20	Quartz
39	0.82	1.35	1.60	0.51	0.84	0.68	-3.50	30	Quartz
40	1.10	1.20	1.50	0.73	0.80	0.87	3.41	40	Quartz
41	1.03	1.44	1.85	0.56	0.78	0.73	0.00	25	Quartz
42	1.15	1.23	1.70	0.68	0.72	0.89	5.24	20	Quartz
43	0.80	1.30	1.80	0.44	0.72	0.65	0.00	30	Quartz
44	0.45	1.30	1.70	0.26	0.76	0.45	-6.80	10	Quartz
45	0.64	1.41	1.70	0.38	0.83	0.54	-6.01	10	Quartz
46	1.00	1.22	1.64	0.61	0.74	0.79	2.56	25	Quartz
47	0.82	1.2	1.50	0.55	0.82	0.71	-1.88	25	Quartz
48	0.73	1.10	1.64	0.45	0.67	0.67	2.10	30	Quartz
49	1.10	1.24	1.80	0.61	0.69	0.82	4.91	25	Quartz
50	1.13	1.30	1.90	0.59	0.68	0.81	4.69	20	Quartz
51	1.25	1.30	1.50	0.83	0.87	0.94	3.60	30	Quartz
52	1.00	1.30	1.82	0.55	0.71	0.75	2.44	30	Quartz
53	0.90	1.42	1.60	0.56	0.89	0.71	-4.32	30	Quartz
54	0.90	1.24	1.60	0.56	0.78	0.74	2.54	30	Quartz
55	0.70	1.03	1.50	0.47	0.69	0.68	1.88	25	Quartz
56	0.72	1.30	1.612	0.44	0.80	0.63	-3.25	20	Quartz
57	0.90	1.10	1.70	0.53	0.65	0.76	4.72	40	Quartz
58	0.80	1.12	1.40	0.57	0.80	0.74	-5.83	25	Quartz
59	1.10	1.34	1.70	0.65	0.79	0.81	1.55	40	Quartz

60	1.94	1.30	1.80	0.52	0.72	0.72	1.56	25	Quartz
61	1.10	1.64	1.90	0.58	0.86	0.73	-3.00	20	Quartz
62	0.90	1.43	1.62	0.56	0.88	0.70	-4.25	30	Quartz
63	0.90	1.40	1.60	0.56	0.88	0.71	-3.81	40	Quartz
64	1.00	1.40	1.70	0.59	0.82	0.75	-2.21	20	Quartz
65	0.63	1.13	1.73	0.37	0.66	0.59	8.82	20	Quartz
66	0.87	1.50	2.00	0.44	0.75	0.64	-1.32	20	Quartz
67	0.70	1.14	1.41	0.50	0.81	0.67	-2.41	30	Quartz
68	0.95	1.00	1.64	0.58	0.61	0.82	7.38	25	Quartz
69	0.74	1.37	1.72	0.43	0.76	0.63	-1.66	20	Quartz
70	0.54	1.25	1.70	0.32	0.74	0.51	-3.53	10	Quartz
71	0.80	1.05	2.10	0.38	0.50	0.66	8.08	20	Quartz
72	0.70	1.30	2.00	0.35	0.65	0.57	1.11	20	Quartz
73	1.10	1.50	1.75	0.63	0.86	0.77	-1.84	30	Quartz
74	0.90	1.10	1.84	0.49	0.60	0.75	5.87	30	Quartz
75	0.73	1.50	1.53	0.48	0.98	0.61	-9.69	25	Quartz
76	0.92	1.13	1.60	0.58	0.71	0.78	3.32	40	Quartz
77	0.10	1.30	1.70	0.10	0.76	0.17	-42.5	40	Quartz
78	0.70	1.30	1.65	0.42	0.79	0.62	3.10	10	Quartz
79	0.82	1.30	1.80	1.46	0.72	0.66	2.24	30	Quartz
80	0.90	1.10	1.62	0.56	0.68	0.77	4.00	30	Quartz
81	0.84	0.90	1.40	0.60	0.64	0.83	6.55	30	Quartz
82	0.74	1.12	1.74	0.43	0.64	0.66	2.82	20	Quartz
83	0.53	1.11	1.70	0.31	0.65	0.54	1.37	10	Quartz
84	0.74	1.20	1.56	0.47	0.77	0.66	-1.29	20	Quartz
85	0.80	1.05	1.60	0.50	0.66	0.73	3.75	30	Quartz
86	0.90	1.40	1.42	0.63	0.99	0.74	-7.28	40	Quartz
87	0.85	1.45	1.55	0.55	0.94	0.68	-6.51	50	Quartz
88	1.20	1.20	1.31	0.92	0.92	0.97	5.47	25	Quartz
89	0.82	1.10	1.30	0.63	0.85	0.78	-1.32	40	Quartz
90	0.80	1.30	1.60	0.50	0.81	0.68	-2.50	40	Quartz
91	1.10	1.50	1.80	0.61	0.83	0.77	-1.77	30	Quartz
92	0.62	1.00	1.54	0.40	0.65	0.63	2.16	20	Quartz
93	0.82	1.20	1.70	0.48	0.71	0.69	1.41	25	Quartz
94	0.80	1.14	1.73	0.46	0.66	0.69	2.91	20	Quartz
95	0.80	1.00	1.30	0.62	0.77	0.79	1.63	30	Quartz
96	0.70	1.03	1.62	0.43	0.64	0.66	3.27	25	Quartz
97	1.05	1.05	1.90	0.55	0.55	0.79	9.05	30	Quartz
98	0.60	1.10	1.42	1.42	0.77	0.61	-2.61	20	Quartz
99	0.70	1.10	1.50	0.47	0.73	0.68	0.00	25	Quartz
100	0.50	1.20	1.74	0.29	0.69	0.49	-2.25	10	Quartz

Table 3.Minerals, Rock Fragments And Mica In The Sandstones of Okunmi And Abaja Road ,Lokoja And Patti Formations

Sandstones	Q_m	Q_P	Q_T	F_M	F_O	F_P	F_T	Mica	R.F	Cement
AR 10	99.00	1.00	100	0.00	0.00	0.00	0.00	0.00	0.00	present
AR 9	99.05	0.95	100	0.00	0.00	0.00	0.00	0.00	0.00	present
AR 8	98.40	0.86	99.26	0.00	0.00	0.00	0.00	0.00	0.74	present
AR 7	99.01	0.99	100.00	0.00	0.00	0.00	0.00	0.00	0.00	present
AR 6	98.27	0.58	98.84	0.00	0.00	0.00	0.00	0.00	1.16	present
OK 5	84.00	1.79	85.79	3.56	1.93	7.52	13.01	0.20	1.00	present
OK 4	83.33	1.28	84.62	1.28	0.00	11.54	12.82	1.00	1.55	present
OK 3	84.24	1.82	86.06	3.64	1.82	5.46	10.91	0.02	3.01	present
OK 2	78.43	1.96	80.39	6.86	1.96	8.82	17.64	0.01	1.96	present
OK 1	83.33	3.92	87.25	2.94	0.00	8.82	11.76	0.02	0.97	present

OK is Okunmi and AR is Agbaja road. Q_m is monocrystalline quartz, Q_p is polycrystalline quartz and Q_T is total quartz, $F_m$is microcline feldspar, $F_o$is orthoclase feldspar and F_T is total feldspar. R.F is rock fragment .The essential constituents (Q, F and R.F) were recalculated to 100%

Table 4.Minerals, Rock Fragments and Mica in the Sandstones Of Yewuti Sabo, Patti Formations

Sandstones	Q_m	Q_P	Q_T	F_M	F_O	F_P	F_T	Mica	R.F	Cement
L10R	90.00	-	90.00	5.00	1.00	3.00	9.00	0.00	1.00	present
L10Q	90.00	-	90.00	6.00	0.00	3.00	9.00	0.02	0.98	present
L10N	85.00	-	85.00	5.00	3.00	7.00	15.00	0.00	0.00	present
$L10L^1$	90.00	-	90.00	10.00	0.00	0.00	10.00	0.00	0.00	present
L10L	80.00	-	80.00	8.00	2.00	8.00	18.00	0.01	1.99	present
L10K	85.00	-	85.00	6.00	2.00	6.00	14.00	0.00	1.00	present
L10H	90.00	-	90.00	3.00	2.00	5.00	10.00	0.00	0.00	present
L10G	90.00	-	90.00	6.00	0.00	2.00	8.00	0.05	1.95	present
L10F	90.00	-	90.00	4.00	1.00	3.95	8.95	0.05	1.00	present
L10E	80.00	-	80.00	7.00	2.00	9.00	18.00	0.00	2.00	present
L10D	85.00	-	85.00	4.00	2.00	6.00	12.00	1.00	2.00	present
L10C	90.00	-	90.00	6.98	0.00	2.00	8.98	0.02	1.00	present
L10B	90.00	-	90.00	2.00	2.00	5.97	9.97	0.03	0.00	present
L10 A	90.00	-	90.00	9.00	0.00	0.00	9.00	0.00	1.00	present

L10 A to L10R are location sample numbers. Q_m is monocrystalline quartz, Q_p is polycrystalline quartz and Q_T is total quartz$F_m$is microcline feldspar,$F_o$is orthoclase feldspar and F_T is total feldspar. R.F is rock fragment The essential constituents (Q, F and R.F) were recalculated to 100%

V. DISCUSSIONS

Origin

Thequantityof quartz, feldspar and rock fragments have been used to construe the tectonic setting of a basin [17].Accordingly, we inferred the tectonic setting of Bida Basin to becraton interior(fig.2).Also, [5] and [18] have linked heavy minerals with source rocks of sediments. Similarly, we associated the heavy minerals to provenance, and concluded that the presence of Zircon and Tourmaline suggests igneous rocks and low grade metamorphic rocks while the occurrence of Staurolite and Rutileindicate high-grade metamorphic rocks as the sources of the sediments of the studied area.

Weathering and Transport History

Factors such as textural features, heavy mineral stability and mineralogical maturity indices were considered in an attempt to deduce the weathering history. According to [5] and [13], ZTR indices less than 75% indicate mineralogical immature to sub-mature sediments, and greater than 75% suggest mineralogical matured sediments. The values obtained in this study ranges from 29% to 74%, with an average of 55.4%. They are lower than the discriminant value of 75%. These imply that the sediments of Patti Formation are miner logically immature to sub-mature.

Also, the heavy mineral stability index was used by [5], [19] and [20] to distinguish heavy minerals into unstable, moderately stable, stable, and ultra-stable minerals. The model was adopted in this work to classify the heavy minerals. The ultra-stable components include Zircon, Tourmaline and Rutile, and the stable one is Staurolite. They have a combined percentage proportion of 72% while the percentage composition of other heavy minerals is 28%.

The texture (angular to sub-angular shapes) of heavy minerals and quartz grains indicate that physical weathering and abrasion was ephemeral. It also implies that the sediments have undergone a short transport process and were deposited close to their sources and might not have been reworked. It could be that chemical weathering of the source rocks might have taken place and dissolved the heavy minerals according to their susceptibility and with no or little physical weathering and abrasion the shapes of the mineral grains appear angular to subangular. The relatively high percentage composition of other heavy mineral groups amidst the predominantly ultrastable, and stable groups suggest that degree of weathering was not sufficient to completely dissolve the other heavy minerals.

Paleoenvironment

Pebble sizes and the derived quantities such as maximum projection sphericity index(M.P.S.I)and oblate-prolate (OP) index have been used by [16] to distinguish environments. They used the sphericity0.65 to 0.66 to differentiate river sediments from beach sediments. The environmental discrimination parameter was used to establish the depositional environments for the Patti Formation by plotting M.P.S.I against pebble sizes, and M.P.S.I against OP index (fig. 3a and b.).Most of the pebbles plotted within the rivers zone while others are within the beach zones. These indicate that the pebbles of Patti Formation are dominantly fluvial environment and others are beach environment.

Diagenesis

[6] shows the interplay between grain packing, size, shape, sorting and degree of compaction of sediments. Evidences of post depositional changes observed in this study are compaction and cementation. Compaction resulted to the formation of sutured contacts among grains of sandstone samples from Okunmi and Yewuti Sabo. The floating grains of rock samples from Agbaja indicate lack of physical compaction. Chemical modifications of sediments after deposition and burial lead to formation of cements. Precipitation of iron oxide cement could be a result of reactions between the grains, pore water and the dissolved ions in the pore water. Also, overgrowths are quartz cements formed from chemical processes that took place on the crystals of existing detrital quartz grains.

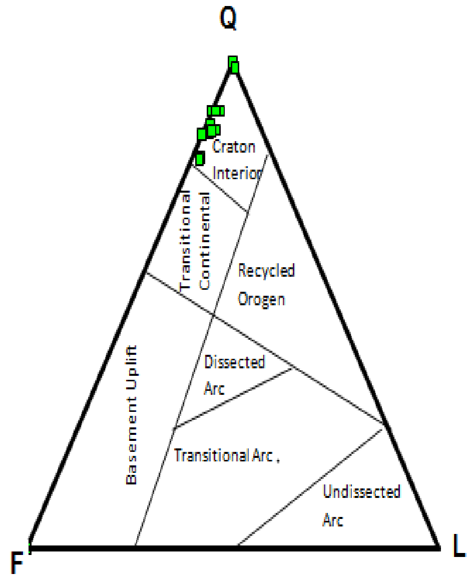

Fig.2. QFL diagram of the tectonic field of sandstones from Patti Formation, after [17]. All the samples fall within the field of craton interior.

Q-total Quartz, F-Feldspar and L-lithic rock fragments

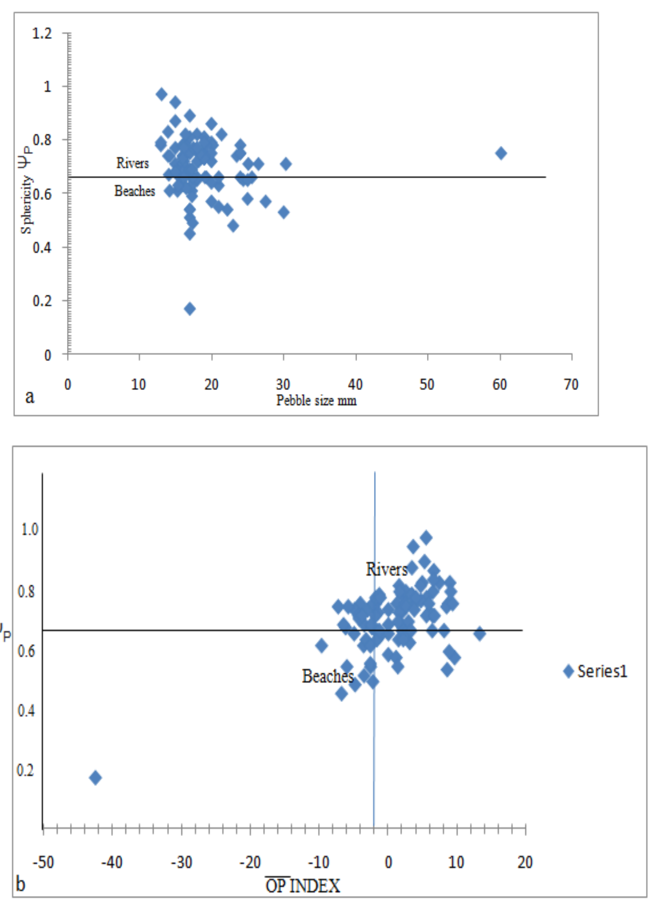

Fig.3. Bivariate plots; a. M.P.S.I Vs Pebble Size and b. M.P.S.I Vs OP index, after [16].

VI. CONCLUSION

The study of the sandstones and pebbles focused on sedimentary processes. Mixed provenance for sediments was inferred. Zircon and Tourmaline are associated with Igneous and low grade metamorphic rocks while Saturolite and Rutile are linked to high grade metamorphic rocks. Furthermore, absence or low degree of physical weathering and abrasion of sediments was confirmed by the textural features (shapes) of the grains. The shapes also revealedshort transport history. Compactions, precipitation of cements and overgrowths are known post depositional changes in the sediments. The measured morphometric data and derivatives gave values which were compared with environmental discriminatory standard figures to deduce that the pebbles are rivers and beach environments. We concluded that compaction led to close grain packing and would have reduced the pore spaces. Formation of cements and overgrowths shows chemical processes and growth within the sediments.

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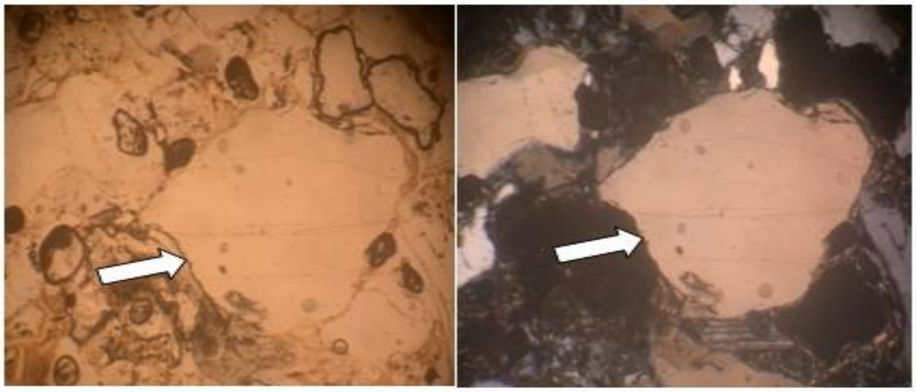
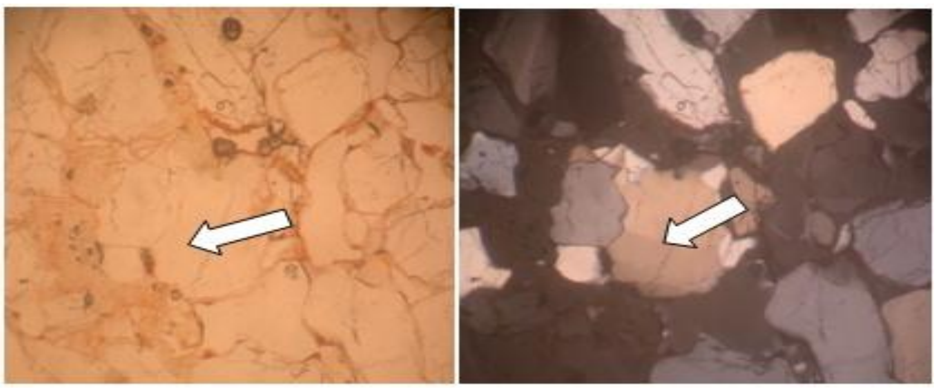
APPENDIX, PLATES 1-6



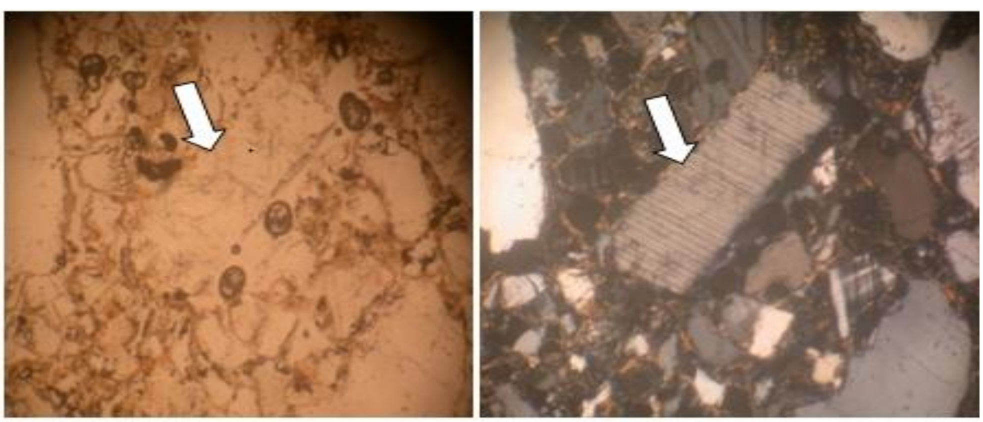
a b

Plates 1. Photomicrograph of the sandstones from the Lokoja Formation, Okunmi section; Arrows point at thin black rim of iron oxide cement at the edges of subrounded, monocrystalline quartz grains.An angular grain is seen at the top left corner, magnification x 40; a. PPL and b. XPL.



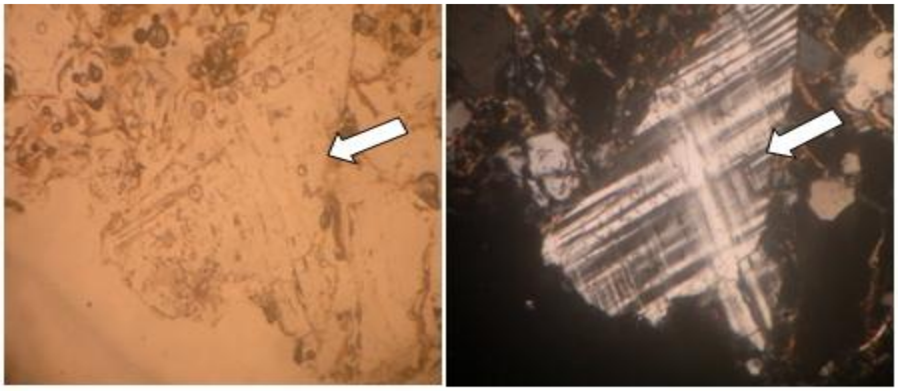
a. b.

Plates 2. Photomicrograph of the sandstone from the Patti Formation, Agbaja road section;polycrystalline quartz grain at the center of view; magnification x 10; a. PPL and b. XPL



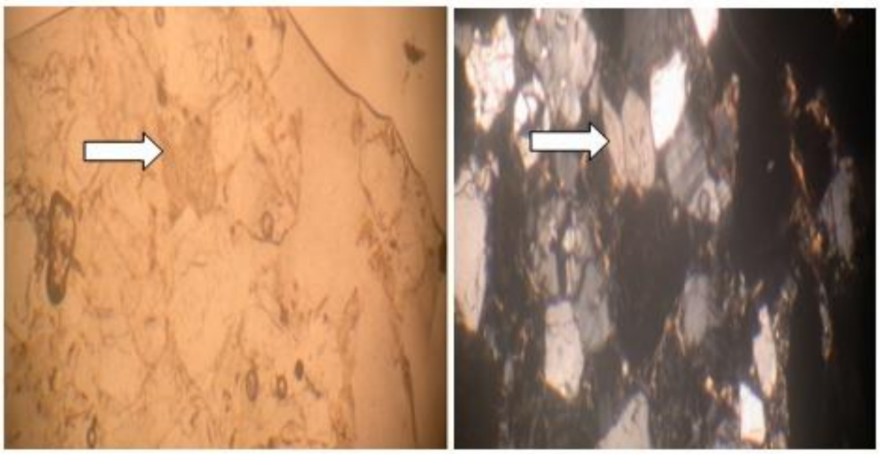
a b

Plates 3. Photomicrograph of the sandstone from the Lokoja Formation, Okunmi section, plagioclase feldspar with multiple twinning under crossed polar at the center of view; magnification x10; a. PPL, b. XPL



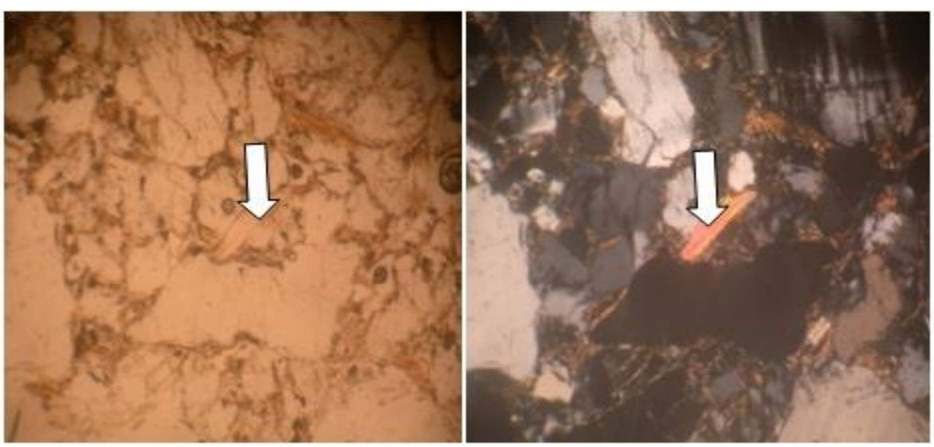
a b

Plates 4.Photomicrograph of the sandstone from the Lokoja Formation, Okunmi section; microclinefeldspar with cross-hatched twinning under crossed polar, magnification x 40; a PPL, b XPL



a. b.

Plates 5.Photomicrograph of the sandstone from the Lokoja Formation, Okunmi section.
Arrow points at rock fragment; magnification x10; a PPL, b XPL



a b

Plate 6. Photomicrograph of the sandstone from the Lokoja Formation, Okunmi section. Muscovite in the center of the field of view, magnification x 10; a. PPL, b. XPL